National Aeronautics and Space Administration

Goddard Earth Science Data Information and Services Center (GES DISC)

ACOS Level 2 Standard Product Data User's Guide, v3.3

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Goddard Space Flight Center
Greenbelt, Maryland

Jet Propulsion Laboratory
Pasadena, California

Prepared By:

Gregory Osterman, JPL
ACOS, OCO-2 Science Validation Lead

Annmarie Eldering, JPL
OCO-2 Deputy Project Scientist

Charles Avis, JPL
ACOS, OCO-2 Science Data Operations System

Christopher O'Dell, CSU
ACOS, OCO-2 Algorithm Team

Elmain Martinez, JPL
ACOS Science Data Operations System

David Crisp, JPL
OCO-2 Science Team Lead

Christian Frankenberg, JPL
ACOS, OCO-2 Algorithm Team

Brendan Fisher, JPL
ACOS, OCO-2 Validation Team

Debra Wunch, Caltech
ACOS, OCO-2 Validation Team

Revision History

Revision Date	Changes	Author
1 October 2010	Initial Release	C. Avis
20 December 2010	Updates to most sections including changes to ACOS metadata/elements based on the v2.8.00 delivery. Updated quality provided by G.Osterman.	E. Martinez
30 October 2011	Complete revision of document. Includes updates for Build 2.9	E. Martinez
29 November 2011	Rev B: Updated links to Mirador, corrected typos	E. Martinez
7 December 2011	Rev C: corrected typo on page 17 and added additional instructions on how to get data in section 4. ACOS release v2.9	E. Martinez
26 October 2012	Rev D: Updated to further describe experience with v130130 data, and the preliminary experience with v15015x. Additional information about biases between Gain H and Gain M has been added. Errors associated with geolocation uncertainties also added. ACOS release v2.9	D. Crisp
29 October 2012	Rev E: Updated for ACOS release v2.10	C. O'Dell, G. Osterman, A. Eldering, D. Crisp, C. Avis
13 June 2013	Rev F: Updated for ACOS release v3.3	C. O'Dell, G. Osterman, B. Fisher, C. Frankenberg, C. Avis
21 June 2013	Rev G: Updates to Section 2.5.1 and Table 2	C. O'Dell, G. Osterman

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1. Introduction

1.1. Scope and Background

This document is intended to provide an overview of the v3.3 Atmospheric CO_2 Observations from Space (ACOS) data product, key features and issues, preliminary validation information, recommendations on data usage, as well as background on the Greenhouse Gases Observing Satellite (GOSAT) mission measurements and the ACOS algorithm. The data from the GOSAT satellite is provided through a joint effort by the Japan Aerospace Exploration Agency (JAXA), the National Institute for Environmental Studies (NIES) and the Ministry of the Environment (MOE). The later sections provide the reader with information on filename conventions and a detailed guide on the format and fields in the HDF product.

This is the fourth 'public release' of ACOS data, the previous released version being v2.9, which was released in November 2011. The ACOS v2.10 data was released for Science Team (only) use in October 2012 as an interim build between v2.9 and v3.3. The v2.8 and v2.9 data are described in a series of validation papers published in 2011 and 2012. This document updates the findings from those papers as they apply to v3.3, and gives general information on the use of ACOS data. Please note that the v3.3 data is continuing to be evaluated. We have found that land gain M data and ocean glint data have some deficiencies in this version, and should be used only with heightened caution.

1.2. Document Overview

The remainder of this section describes the usage of the ACOS data. Section 2 provides details of the differences in this version, product characteristics, validation status, key data fields and ends with recommendations for data analysis. Section 3 provides background information on the GOSAT mission, ACOS file and data conventions, and a complete listing of metadata elements in the v3.3 ACOS data product. Section 4 lists tools to view and search the data products. Section 5 lists contact information for both GOSAT and ACOS data, and the last section lists acknowledgements and relevant publications.

Figure 1 shows the flow of the ACOS data processing scheme. The processing begins with the raw interferometric files (called Level 1A or L1A) produced by JAXA, who then produce raw spectra (called L1B). The raw Level 1B (L1B) files are converted into calibrated radiance spectra by the ACOS team (called ACOS L1B), which are then processed through its retrieval algorithm to produce the raw X_{CO2} values (Level 2 or L2). These L2 files should then be properly filtered and bias-corrected by the data user before being used in scientific studies. Sections describing each step of the flow chart are listed in the figure.

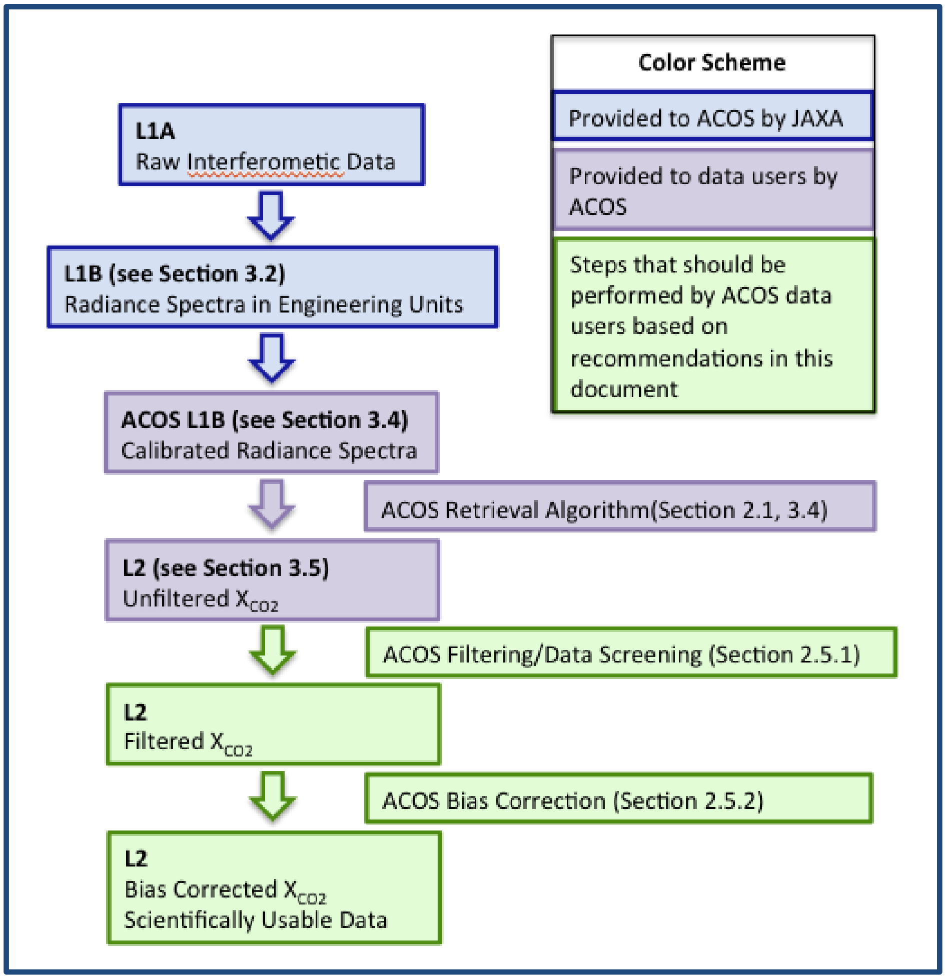

Figure 1. The data flow starting from the raw interferometric data produced from the GOSAT instrument through to the data that should be used for scientific study. Blue boxes (arrows) contain data files (algorithms) provided by JAXA, purple boxes and arrows are from the ACOS/OCO-2 project. Green boxes and arrows represent items that are to be performed by the data user. Note that the bias-corrected X_{CO2} data that is to be used for scientific purposes is filtered and bias-corrected by the data user.

Please note that this is an interim document only. Build 3.3 retrievals continue to be evaluated, and the guidance provided herein is both preliminary and incomplete. In particular, land gain M data and ocean glint data have revealed some potential deficiencies in this version, and should be used only with heightened caution. This document will be updated once a more detailed analysis of the v3.3 retrievals is completed.

1.3. Data Usage Policy

These data have been produced by the ACOS project, and are provided freely to the public. The ACOS project has been made possible by the generous collaboration with our Japanese colleagues at Japanese Aerospace Agency (JAXA), National Institute for Environmental Studies (NIES), and the Ministry of the Environment (MOE). The L1A data have been made available for this project through an RA agreement between the GOSAT Three Parties and Caltech. To improve our product and have continued support for this work, we need user feedback and also

have users acknowledge data usage. Therefore, we request that when publishing using ACOS data; please acknowledge NASA and the ACOS/OCO-2 project.

- Include OCO-2 as a keyword to facilitate subsequent searches of bibliographic databases if it is a significant part of the publication
- Include a bibliographic citation for ACOS/OCO-2 data. The most relevant citations currently are Wunch et al (2011), O'Dell et al (2012) and Crisp et al. (2012).
- Include the following acknowledgements: "These data were produced by the ACOS/OCO-2 project at the Jet Propulsion Laboratory, California Institute of Technology, and obtained from the ACOS/OCO-2 data archive maintained at the NASA Goddard Earth Science Data and Information Services Center."
- Include an acknowledgement to the GOSAT Project for acquiring these spectra.
- We recommend sending courtesy copies of publications to the OCO-2 Project Scientist, Michael.R.Gunson@jpl.nasa.gov.

2. V3.3 ACOS L2 Data Products

2.1. Differences Between v3.3 and v2.10/v2.9

The following is a summary of the key L1B changes made in v3.3 compared to v2.10. Note that more details of the L1B versions are included in Section 3.2.

Changes to the L2 products are as follows:

- Significantly affecting the retrieval results
    - Updated spectroscopy – ABSCO Coefficients V4.1.1
    - Residual Fitting of first EOF (per band) replaces empirical noise
    - Reduced aerosol optical depth a priori value to 0.05.
    - Significantly tightened surface pressure constraints, ±1 hPa (roughly equal weight between data & prior)
    - Fit explicitly for fluorescence over land from O_2A band
    - Utilize a consistent L1B data version (v150151)
    - Updated radiometric calibration & degradation.
- Within the code
    - Updates to radiative transfer scheme (dedicated 2-stream solver)
    - Updated solar model
- Spectroscopy
    - Version 4.1.1 ABSCO tables used in retrieval software

2.2. Validation Status

The version 3.3 ACOS X_{CO2} data product has undergone a preliminary validation using roughly 24 months of data. The validation now includes both H and M gain data over land, as well as glint data over water. Because of a technical error, the amount of usable glint data is down significantly over previous versions of the data product (see Section 2.3). Validation against ground based TCCON data shows an increase in mean biases and a reduction in scatter as compared to the V2.9 data (see Wunch et al., 2011 for ACOS validation methodology against data from the TCCON instruments).

Figure 2 shows a history of a comparison of the zonal mean X_{CO2} measured by TCCON and GOSAT (ACOS). The comparison is for the month of July 2009 and shows a comparison of latitude variation in the difference between ACOS and the TCCON data. Table 1 gives an estimate of the monthly bias between ACOS and the ground based data for each TCCON site. Figure 3 shows a histogram of the differences between TCCON and ACOS estimations of X_{CO2}. The mean bias is now 1.34 ppm, as compared to ~0.1 ppm for v2.9 and ~-0.7 ppm for v2.10. This large change in the global bias is primarily caused by a change in the CO2 absorption cross sections in the 2.06 micron band. For v3.3, X_{CO2} retrievals using the 2.06 micron band were systematically ~1% lower than those obtained using the 1.61 micron CO_2 band. The cause for this discrepancy is currently unknown. To yield more consistent results in the two bands and improve retrieval algorithm convergence, the 2.06 micron CO2 cross sections were scaled by a factor of 0.99. This change served its purpose, but introduced the observed bias in the v3.3 product. The root cause of the bias between the 1.61 and 2.06 micron retrievals is currently under investigation.

Figure 4 shows the bias between v3.3 ACOS X_{CO2} and TCCON for the Lamont site alone, which has the most complete data record. It shows the mostly positive bias in the values of (ACOS-X_{CO2}) for the ACOS time period. Overall, the amplitude of the seasonal cycle of the bias for v3.3 is smaller than that from v2.9 by about a factor of two (comparison not shown)

The basic approach for deriving both filters and bias-correction algorithms in v3.3 is similar to v2.9, but uses an expanded validation data set that includes not only TCCON and the assumption that there is low spatial and temporal variability in southern hemisphere Xco_2 south of 25°S, but now also a model-based validation data set. The model-based data set includes forward model runs of a combination of transport models and priors, for a total of seven model runs. All priors have been optimized against ground-based (flask or in-situ) CO_2 data through the end of 2010. For each ACOS sounding, the mean of all seven models (the ensemble mean) is taken to be the true value. Only ACOS soundings for which all models are within 1 ppm of the model mean are used; i.e., the models must mostly agree, in order to consider the "true" X_{CO2} value to be known for a given location and time. This approach has the advantage that it yields Xco_2 model results to compare with over much of the world's oceans, as well as over previously unused regions such as the northern subtropical deserts.

Results of the v3.3 filter analysis and bias correction methodology will be given in Sections 2.5.1 and 2.5.2, respectively.

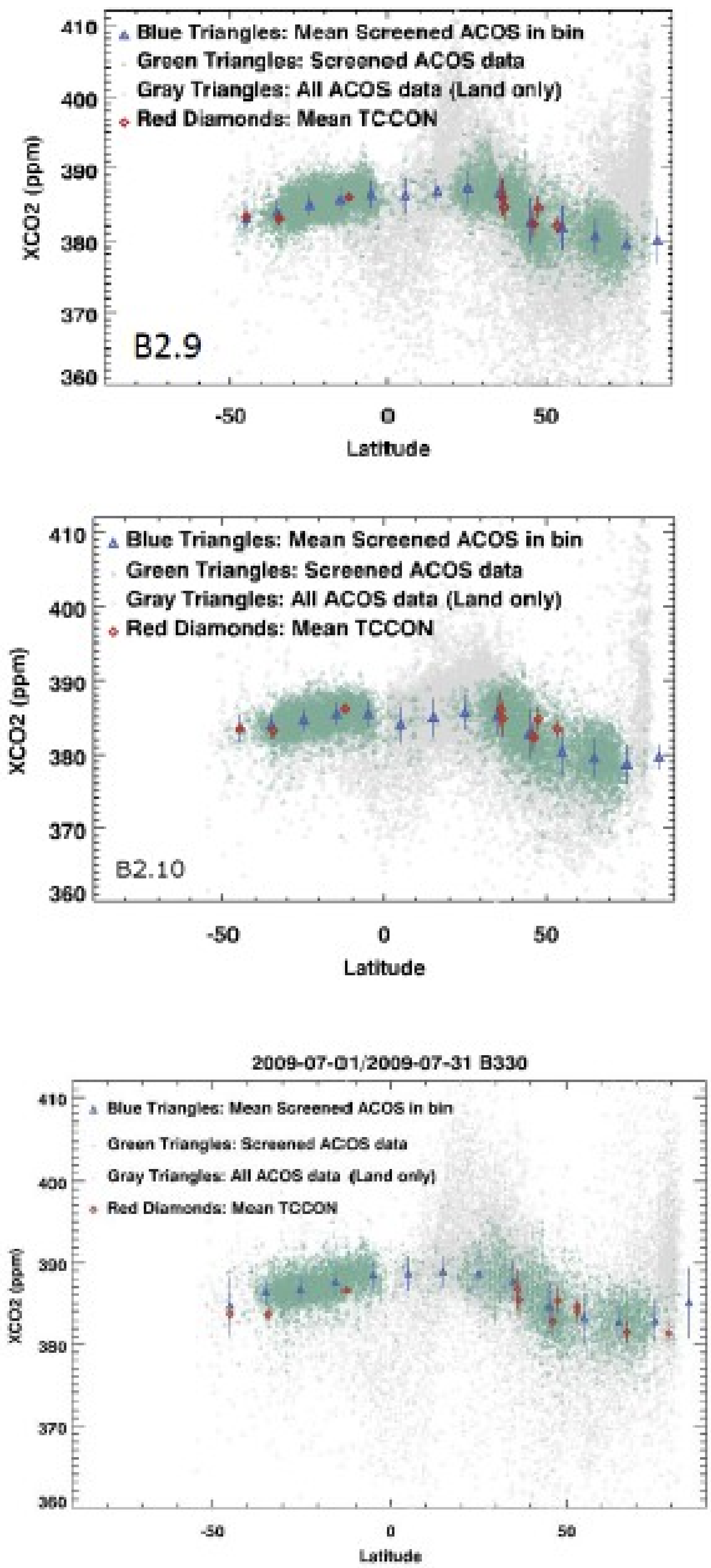

Figure 2. Comparison of ACOS v2.9 (top panel), v2.10 (middle panel) and v3.3 (bottom panel) X_{CO2} data compared to TCCON. The bias seen in v3.3 relative to TCCON is increased over that seen in v2.9.

Table 1: Total mean bias between ACOS v3.3 and TCCON data (Column 2) and monthly mean bias (calculated as ACOS-TCCON).

Site	Mean Bias	2009 July	2009 Aug	2009 Sep	2009 Oct	2009 Nov	2009 Dec	2010 Jan	2010 Feb	2010 Mar	2010 Apr	2010 May	2010 June	2010 July
Sodankyla		0.26	2.96									3.2	2.2	3.1
Bialystok	1.22	1.30	1.37							1.23	0.46	0.36	1.79	3.75
Bremen	0.84		1.04	4.82	2.81					1.21	-1.82		-1.0	0.92
Orleans	1.03		1.82	1.44	1.51	1.10	0.06		-2.3	-0.64	3.0		1.94	2.87
Garmisch	2.31	0.53	1.66	1.26	3.01	1.87			-2.19	2.19	-4.65	2.12		3.5
Park Falls	1.16	0.03	0.2	0.28	1.22	1.31				1.43	1.20	1.78		
Lamont	1.13	0.71	1.79	1.97	2.13	1.61	1.08	0.94	-0.97	0.69	0.15	1.61	0.84	1.12
Tsukuba	2.0		1.23	2.55	2.75	1.12	1.83	-0.44	2.66	1.54				
Darwin	0.7	0.95	1.10	0.48	1.94	1.99	1.03							
Wollongong	1.97	2.4	2.85	0.86		1.71	2.89	1.44		1.38	0.59			2.59
Lauder	0.99	2.65	3.65	0.37	2.11	3.82	1.6							0.4

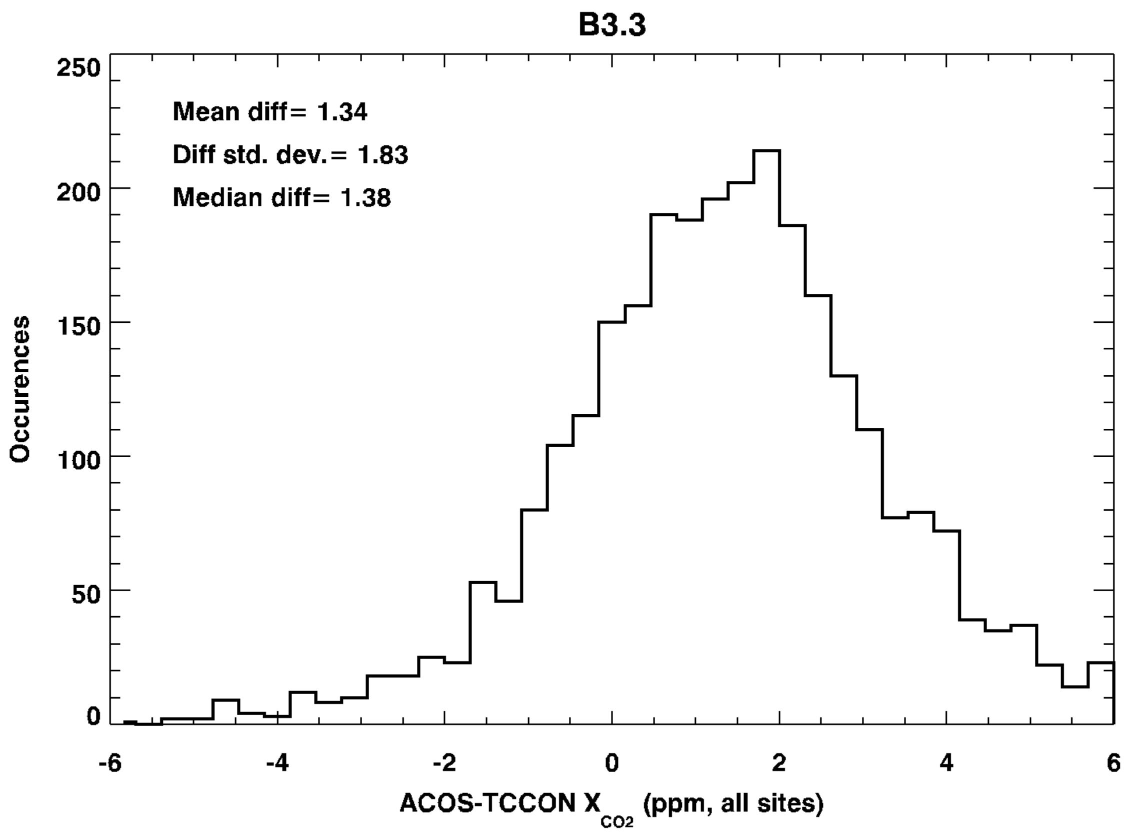

Figure 3. Histogram of the difference between TCCON and ACOS for all TCCON sites used in the analysis (July 2009).

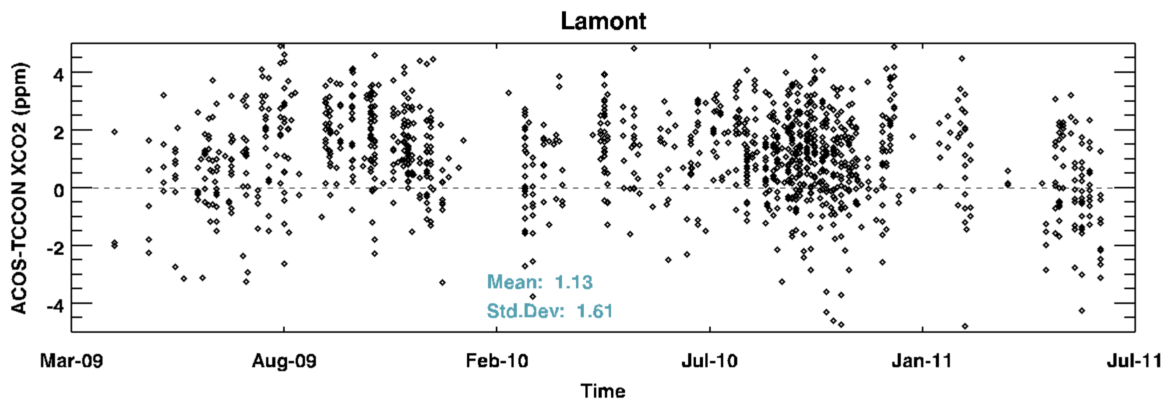

Figure 4. Time series of the bias in ACOS relative to TCCON (TCCON-ACOS) for the TCCON site in Lamont, OK for v3.3.

2.3. Data Description and User Alerts

There are some differences between the results from ACOS software build_id v3.03.00 and those from builds 2.9 and 2.10 (which were very similar).

There remains a fundamental difference between land Medium (M) and High (H) gain data, still driven by the retrieval of a zero-level offset in the oxygen-A band, which itself affects the retrieved surface pressure. Based on initial comparisons to TCCON, Gain M retrievals now exhibit a strong correlation with both Band 1 albedo slope and the retrieved chlorophyll fluorescence. This is a substantial effect. Therefore, gain M retrievals should be treated with extreme caution at this time, until a fuller understanding of their biases is obtained. Ocean data similarly have not performed well in v3.3 and should be avoided at this time. This interim document will provide an initial recommendation for filtering and bias correction of land gain H data (see section 2.5).

Data Completeness/Coverage

- GOSAT L1B Version 150151 was used for all L2 retrievals in v3.3.
- The first three months of GOSAT operations (April-June, 2009) have incomplete operational coverage due to on-orbit calibrations and checkout activities. Routine global coverage begins about 1 July 2009. However, L1B version 150151 includes many more soundings in April-June, 2009, than earlier L1B versions. The v3.3 L2 retrievals therefore also have many more L2 soundings in these months. It is not yet known what confidence can be placed in these early soundings; users should therefore exercise caution when using any data before 1 July 2009.
- Typically data products contain 10-100 useful soundings per orbit, out of the 600-700 L1B soundings collected in an orbit. Note that over 50% of the data is not processed because it does not pass the first cloud screening pre-processing step. A large fraction of data is collected over ocean but not in glint, and thus does not have adequate signal to noise ratios to be processed. Of the ~100 soundings that are processed for each orbit, convergence and quality screens identify about 50% of that data as good in over land in gain H. As stated previously, gain M data should only be used with extreme caution.

As in earlier data products, the range of latitudes where glint measurements can be obtained over the ocean moves north and south during the year, following the sub-solar latitude. Preliminary maps of the v3.3 X_{CO2} with the recommended filtering and bias-corrections applied are shown in Figure 5. As noted above, the yield for glint retrievals in v3.3 is significantly reduced due to a technical error associated with the radiometric degradation correction and will be fixed in the next ACOS release (Figure 6). However, because of this problem, users are encouraged to avoid the ocean glint data for this data version, if possible.

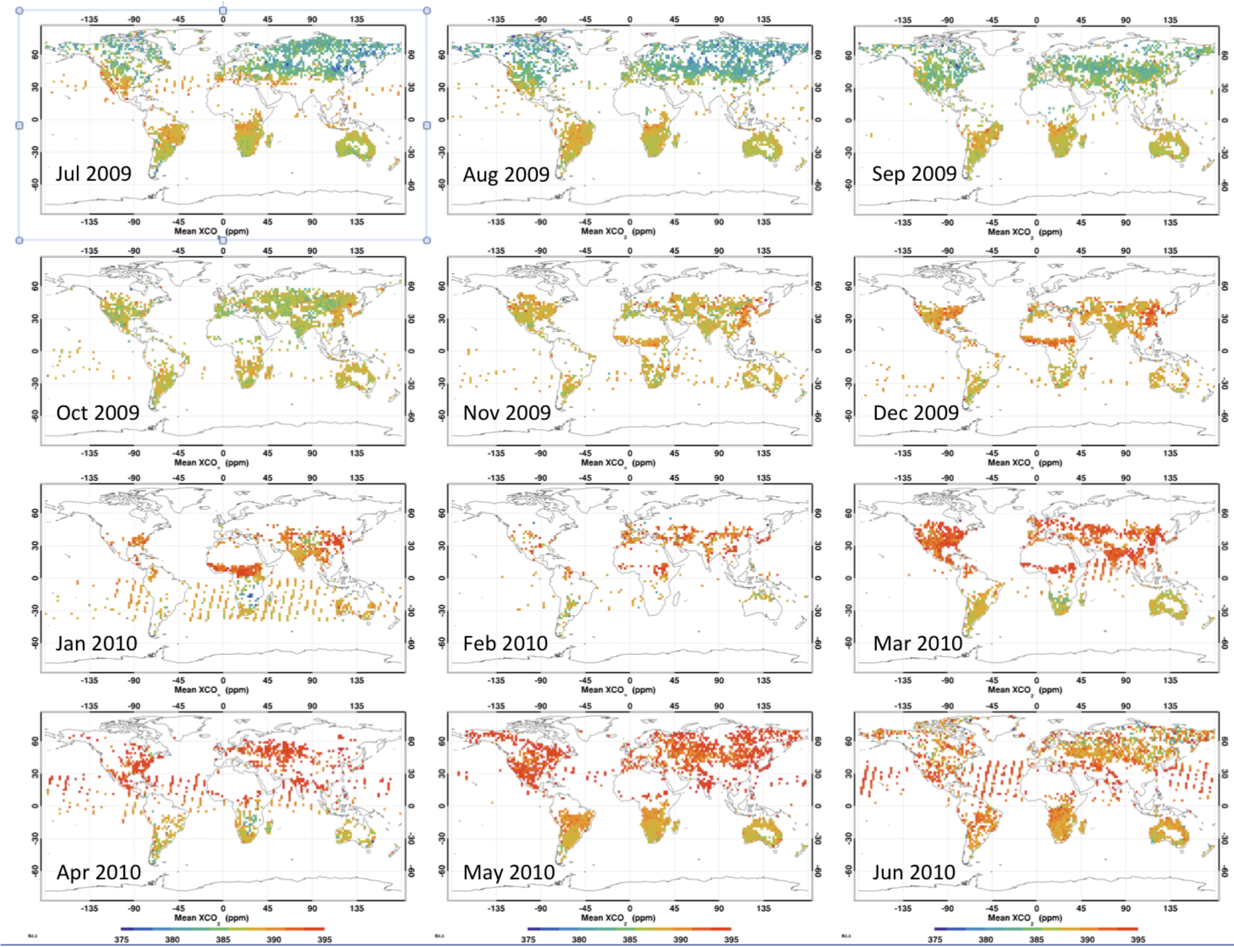

Figure 5. Monthly maps of the ACOS v3.3X_{CO2} data. Each data point contains the average value for X_{CO2} estimates in a 2° x 2° bin for that month that passed all pre- and post-screening filters; the recommend bias correction has been applied.

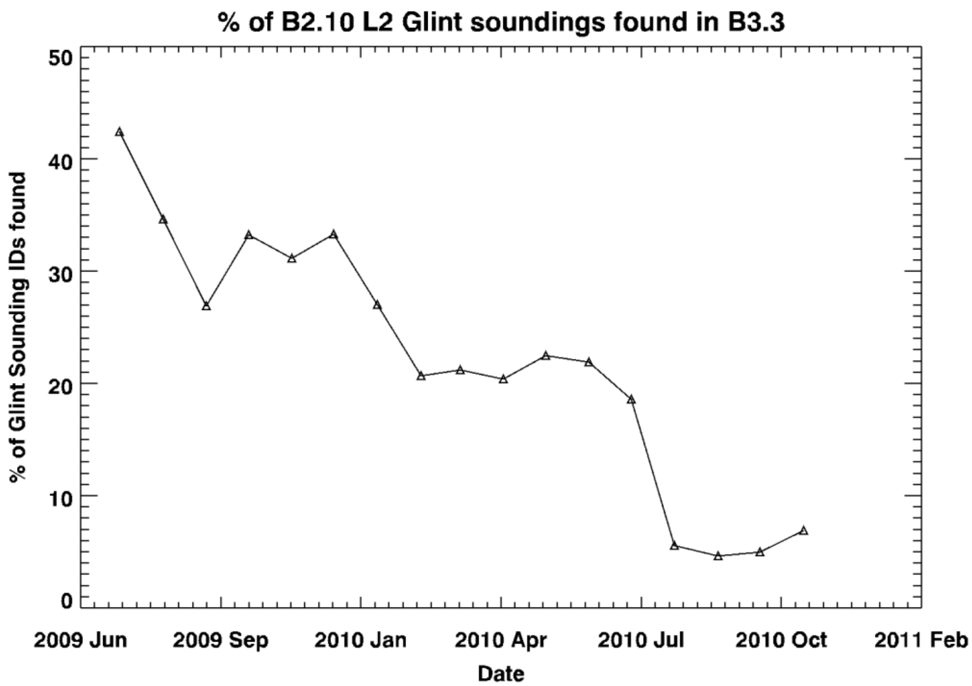

Figure 6. Decrease in v3.3 glint soundings relative to the number in v2.10.

Chlorophyll Fluorescence

A new feature of v3.3 is the implementation of solar-induced chlorophyll fluorescence into the full-physics code as additional state vector element. The main motivation is to reduce a potential bias on X_{CO2}, as outlined in detail in Frankenberg et al. (2012). This product, however, should not be used to look at chlorophyll fluorescence itself, as there is a high interference with other state vector elements (surface pressure, albedo, aerosols). Overall, results look sensible, with the exception of gain M data, where we observe a strong correlation between fitted albedo slope and fluorescence, which also biases X_{CO2}.

The IMAP-DOAS preprocessor performs fluorescence retrievals using Fraunhofer lines only, which is more robust and will be used in a future ACOS data release as the fluorescence product used for scientific investigations. However, in v3.3, the fields reported in the official L2 file have not yet been optimally corrected for zero-level offsets observed in the GOSAT O_2 A-band spectra (see Frankenberg et al, 2011). A separate unofficial fluorescence dataset (monthly ASCII files of single soundings) is available upon request from Christian Frankenberg (Christian.frankenberg@jpl.nasa.gov).

Geolocation Correction

Geolocation Errors: The GOSAT TANSO-FTS has pointing errors that change with time. To track and correct for these variations, JAXA has used images collected from a camera installed within the TANSO-FTS to image the actual bore sight. These images are compared to known topographic features (e.g. shore lines) and with images collected by the TANSO-CAI to track changes in the intended TANSO-FTS pointing. Pointing changes are documented in tables and figures (e.g. Figure 7) that are distributed to the GOSAT user community periodically. All current pointing estimates in the v2.9 product were corrected using geolocation correction tables delivered in late 2010. The pointing offsets changed abruptly in late December 2010. The values used in v2.9 overestimate the pointing offsets through July 2011 by about a factor of 3. TANSO-FTS pointing offsets have changed more than a dozen times since then, but have mean values near those adopted for v2.9 (Figure 7). The values developed for v2.9 have not changed and are applied for v3.3 as well.

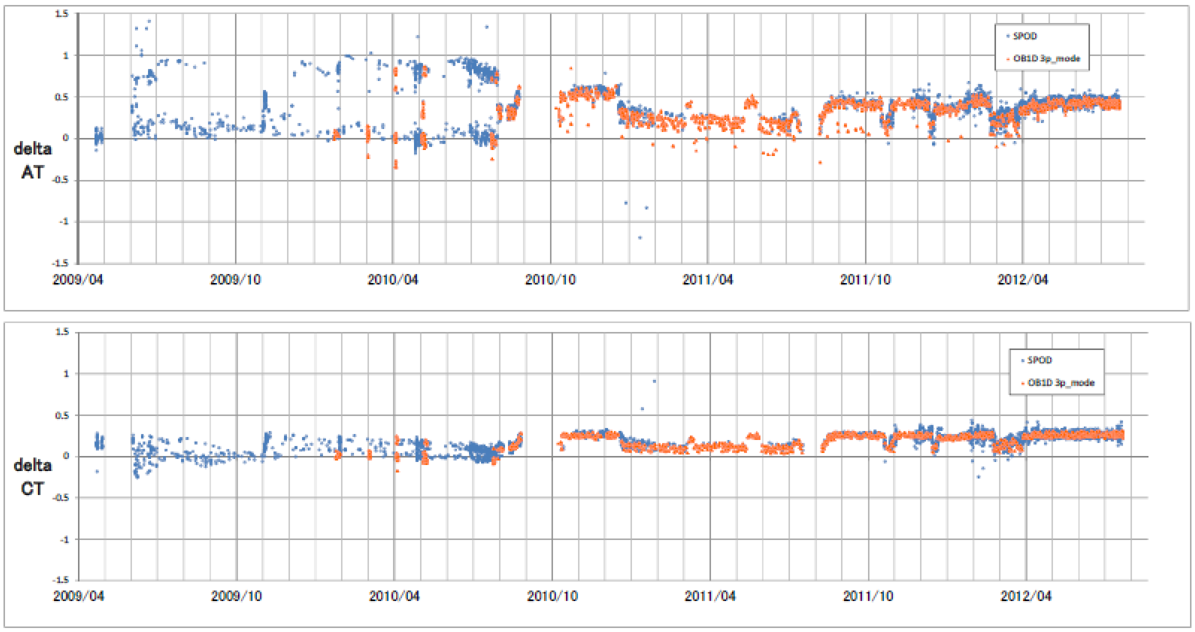

Figure 7. Time dependent pointing errors in the Along-Track (delta AT) and Cross-Track (delta CT) directions between April 2009 and August 2012 for the Specific Point Observations (SPOD) and Lattice Point Observations (OB1D). The change from 5 cross-track points to 3 cross-track points on 1 August 2010 substantially reduced the scatter in the pointing errors. This figure uses the ACOS v2.9 product which assumes a constant offset for all data taken in 3- and 5-point mode. All results for 3-point mode use the offsets estimated for November 2010.

Cloud Screening

- To further reduce the computation time of retrievals containing clouds, the cloud screening algorithm is used to identify and reject soundings prior to the L2 retrieval process. The current cloud screening algorithm performs a fast, Oxygen A-band only clear-sky retrieval for surface pressure, surface albedo, temperature offset and dispersion multiplier. The retrieved surface pressure and albedo information are combined with the χ^2 goodness-of-fit statistic and signal-to-noise ratio to determine if a scene is clear(0), cloudy (1), or skipped (2). The difference of this retrieved surface pressure with respect to the prior ECMWF analysis-based estimate serves as the chief filter criterion; this difference must be less than 25 hPa for the sounding to pass the screen. See Taylor et al. (2012) for further details on the Oxygen A-band cloud-screening algorithm (referred to as ABO2 algorithm).

Post-Processing

- No bias correction – the retrieval results in the standard HDF files have not been systematically corrected based upon some known reference source
- No post-processing – the results in the standard HDF files include all soundings whose retrieval converged. Data users are strongly encouraged to perform data screening, a recommendation is provided in section 2.5.1.

***A*veraging Kernels**

- The data files include a column averaging kernel value for each retrieved sounding.
- The normalized Averaging Kernel (retrieval_results/xco2_avg_kernel_norm) for a given pressure level is equal to the non-normalized value (retrieval-results/xco2_avg_kernel) divided by the pressure weighting function at that level. Note that levels are "layer boundaries" and have no thickness. See Appendix A of O'Dell et al. (2012) for details on how these quantities are defined.

2.4. Key Science Data Fields

2.4.1. RetrievalResults/xco2

The Level 2 Standard Product contains the variable X_{CO2}. This variable expresses the column-averaged CO_2 dry air mole fraction for a sounding. Those soundings that did not converge will not be present. These values are determined by a full-physics retrieval and have units of mol/mol.

2.4.2. SoundingHeader/cloud_flag

The Level 2 Standard Product contains the variable *cloud_flag*. This variable expresses the result of an analysis of cloud contamination within a sounding. Every sounding of a granule will have a value: 0 (Clear), 1 (Cloudy) or 2 (Undetermined). The values are determined by an ABO2-band-only retrieval using the ACOS L1B data. The only soundings that will be processed by the L2 software are those with a value of 0 (Clear). However, this does NOT mean that all processed soundings are actually clear. Some cloudy scenes are invariably missed by the ABO2-only preprocessor, but can lead to bad X_{CO2} retrievals. Therefore, users are strongly encouraged to further apply the recommended quality filters given in section 2.5.

2.4.3. RetrievalResults/surface_pressure_fph

The Level 2 Standard Product contains the variable *surface_pressure_fph*. This variable expresses the retrieved atmospheric pressure at the Earth's surface for a given sounding. Those soundings that did not converge will not be present. These values are determined by a full-physics retrieval and have units of pascals.

2.4.4. RetrievalResults/quality_flag

The original intent of the flags provided in the data product was to provide general post-processing screening criteria for the Level 2 ACOS X_{CO2} retrievals. However, detailed science analysis using earlier data versions has shown that a more rigorous screening formulation is necessary to properly screen ACOS data. The ACOS Science team strongly recommends the user screen the data using the method provided in Section 2.5.1 and not the data flags provided in the product when doing science analyses. The retrievals flagged as "good" in the quality_flag field have converged and have not been flagged for Level 1B or retrieval preprocessing issues.

2.5. Science Analysis Recommendations

2.5.1. Recommended Data Screening

An updated screening criteria, incorporating additional data fields, have been developed for v3.3 land gain H retrievals. Because of the new issues identified during the validation of v3.3 data for land gain M and ocean glint retrievals, we only discuss land gain H. Good soundings will be ones that pass all the criteria in Table 2. Analysis shows that approximately 50% of land/gain H converged soundings pass this set of post-retrieval screening criteria.

Table 2: Advanced screening criteria for the L2 in the v3.3 data.

Variable	Criteria
RetrievalResults/outcome_flag	Land gain H 1 or 2
RetrievalResults/aerosol_total_aod	0.01 to 0.2
SoundingGeometry/sounding_altitude_stddev	< 200
IMAPDOASPreprocessing/co2_ratio_idp	0.995 to 1.015
IMAPDOASPreprocessing/h2o_ratio_idp	0.92 to 1.05
ABandCloudScreen/surface_pressure_delta_cld	–825 to 575 (units of Pa)
SpectralParameters/reduced_chi_squared_o2_fph	< 1.5
RetrievalResults/albedo_slope_strong_co2	$> -10.0 \times 10^{-5}$
RetrievalResults/albedo_slope_o2	$< -1.3 \times 10^{-5}$
Blended Albedo	< 0.8

Above, the blended albedo screening parameter is a mixture of two albedo terms in the data product files. High values are indicative of a snow or ice-covered surface. It can be calculated by using the following relationship:

$$\text{blended albedo} = 2.4A_{O2A} - 1.13A_{SCO2} < 1$$

where A_{O2A} is the albedo for the O_2 A band (RetrievalResults/albedo_o2_fph) and A_{SCO2} is the albedo in the strong CO_2 band (RetrievalResults/albedo_strong_co2_fph) as described in Wunch et al. (2011).

2.5.2. Recommended Bias Correction

In addition to a global bias, errors in the X_{CO2} retrievals have been found to spuriously correlate with certain other variables. This has been true in all previous versions of the algorithm. This issue was first explored for v2.8 and v2.9 (Wunch et al., 2011), in which four regression variables were used to correct ACOS (land, gain H) data. No correction was given for land gain M or ocean glint data at that time. This procedure was expanded in the

V2.10 retrievals to also include land gain M and ocean glint soundings. There, two variables were used to bias-correct land soundings, and three were used for ocean soundings.

For v3.3 retrievals, we follow the same methodology but again arrive at different bias-correcting variables and coefficients. This is due to the changes in the algorithm, such as the lowered prior aerosol optical depth and tight prior surface pressure constraint. As for filtering, at this time we only provide bias-correction coefficients for land gain H retrievals. The following bias correction approach is therefore recommended for v3.3 data land, gain H retrievals passing the science screening criteria of section 2.5.2:

$$X'_{CO2} = X_{CO2} - 1.25 \cdot 10^{-3} \cdot (\Delta P_{S,CLD} + 125) + 1.98 \cdot (S_{31} - 0.60) - 1.2$$

where $\Delta P_{S,CLD}$ is the difference between the retrieved and prior surface pressure from the A-band cloud-screen variable, expressed in Pa:

$$\Delta P_{S,CLD} = \text{/ABandCloudScreen/surface\_pressure\_delta\_cld}$$

S_{31} is the ratio of the signal in the strong CO_2 band to that of the O_2A band:

$$S_{31} = \text{signal\_strong\_co2\_fph / signal\_o2\_fph}$$

where both signal variables are contained in the SpectralParameters group in the L2 file. X_{CO2} and X'_{CO2} have units of ppm and represent raw and bias-corrected values, respectively. The two coefficients have been determined by comparisons to both models and TCCON retrievals, and are uncertain to approximately 15%. The bias has been determined exclusively via comparisons to TCCON, and is uncertain to ~ 0.3 ppm.

2.5.3. GOSAT H- and M-Gain Data

The TANSO-FTS on the GOSAT satellite makes measurements in different modes. The different gain modes appear to suffer from slightly different biases, and the gain M biases in v3.3 are particularly uncertain as discussed above. Because of this, filters and bias-correction algorithms have only been developed for land gain H retrievals.

The gain setting can be determined by looking at the "RetrievalHeader/gain_swir" variable in the ACOS data product. Note that this variable has two character string entries per sounding – one for the S polarization and one for the P polarization.

3. Background Reading

3.1. About the GOSAT Mission

The Japanese GOSAT mission was successfully launched on January 23, 2009. The GOSAT prime mission extends five years from the date it was declared operational on April 19, 2009.

3.1.1. Instrument

The primary GOSAT science instrument is the Thermal And Near infrared Sensor for carbon Observation (TANSO). It is a Fourier-Transform Spectrometer (FTS) with 2-axis scanner. The scanner directs light into two sets of detectors within the instrument.

The Short Wave InfraRed (SWIR) detector is designed to measure the spectrum of reflected sunlight from both land and water surfaces. Three spectral regions are covered in two polarizations:

- Band 10.75 - 0.78 µm Oxygen, a.k.a. ABO2
- Band 21.56 – 1.72 µmWeak CO_2, a.k.a. WCO_2
- Band 31.92 – 2.08 µmStrong CO_2, a.k.a. SCO_2

The Thermal InfraRed (TIR) detector is designed to measure the spectrum of thermal radiation from both land and water surfaces. A single spectral region is covered (5.5 – 14.3 µm). The ACOS Level 2 products do not include or utilize any TIR data.

The nominal orbit parameters for the GOSAT satellite are provided in Table 3.

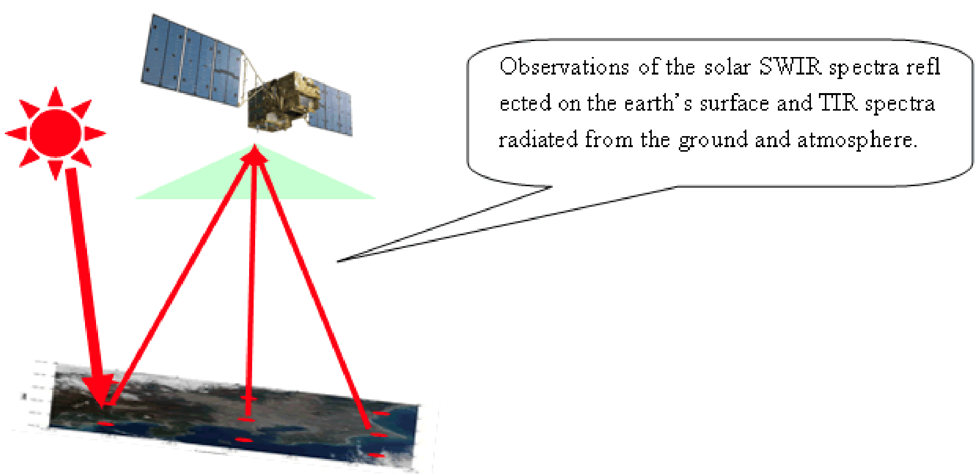

Figure 8. GOSAT Observation Concept

Table 3: Properties of the GOSAT orbit

Orbit Type:	Sun-synchronous, ground track repeat, near-circular orbit
Recurrent period:	3 days
Recurrent orbit number:	44
Revolutions per day:	14+2/3 rev/day
Local sun time at descending node:	12:45 – 13:15 PM
Altitude above equator:	665.96 km
Orbital Period:	98.1 minutes
Inclination:	98.06 degrees
Eccentricity:	0.0 (Frozen orbit)
Longitude at ascending node:	Longitude 4.92 degrees west for orbit #1
Footprint size on ground:	10.5 km circle when Nadir viewing

Path ID Definition

The Path ID identifies the GOSAT orbit tracks on the ground. The detailed characteristics are as follows:

- A path begins at ascending node and extends to the next ascending node
- The ascending node of the Path with an ID of 1 is at longitude 4.92 degrees west
- The path number of the orbit tracks westward sequentially
- Path IDs run from 1 through 44
- Path calculator: https://data.gosat.nies.go.jp/map/html_E/MapPathCalendar.html

Note that Figure 9 illustrates 5-point sampling, which was used from April 2009 through July 2010. Since August 1, 2010, a 3-point sampling mode has been used. This change did significantly reduce the spatial coverage of the GOSAT data.

Points	Interval
1	789 km
3	263km
5 (nominal)	158km
7	113km
9	88km

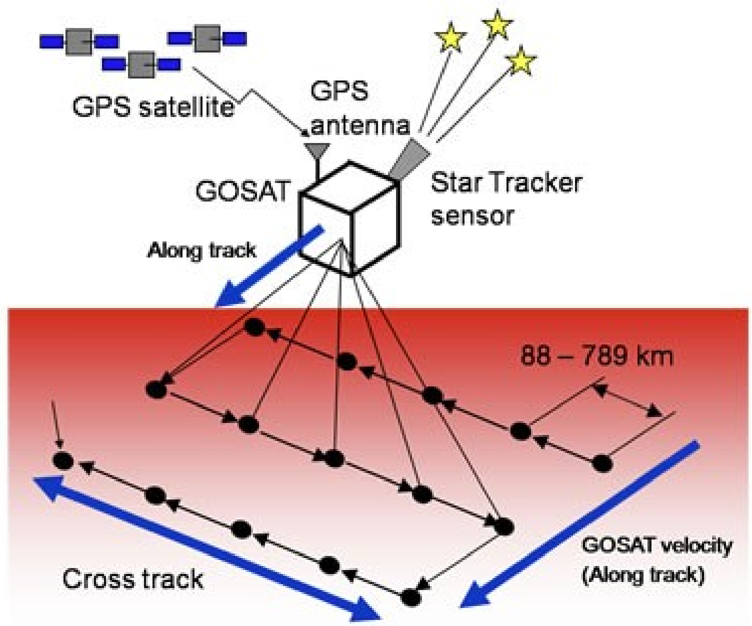

Figure 9. GOSAT TANSO-FTS Observation Details

3.2. GOSAT L1B Releases

The L1B radiance data are provided to the ACOS project by JAXA. As instrument characteristics are better understood, there have been some changes to the L1B data. Table 4 provides a high level view of the L1B versions and key characteristics. Section 3.5.1 shows how the L1B version that was used can be identified in the L2 product file name.

3.3. About the ACOS Task

The ACOS project was part of the Earth System Science Pathfinder (ESSP) Program in the NASA Science Mission Directorate (SMD). The Orbiting Carbon Observatory (OCO) was to have been the first NASA satellite designed to make global measurements of atmospheric carbon dioxide (CO_2) sources and sinks on regional scales at monthly intervals. The failure of the launch system and loss of the observatory therefore represented a setback to NASA's carbon cycle and climate science programs.

In order to meet its stringent CO_2 measurement accuracy requirements, the OCO Science Team developed and implemented several significant advances in ground-based calibration, validation, and remote sensing retrieval methods. These investments were not lost in the OCO launch failure and remain valuable NASA assets.

The OCO and GOSAT Science Teams formed a close partnership in calibration and validation activities. JAXA granted the ACOS Project access to GOSAT's calibrated Level 1B measurements. The ACOS Project applied the OCO calibration, validation, and remote sensing retrieval assets to analyze these GOSAT measurements. These analyses generate the Level 2 data products described herein.

Table 4: Description of the different GOSAT L1B releases.

Version	Period YYMMDD	Changes
Version006006 (P)	090423–090504 090516–090728	• initial version
Version007007 (P)	090405–090409 090419–090429 090716–091029	• SWIR spectrum unit is changed: (V -> V/cm-1) • SWIR phase correction parameter is changed. (Gauss function parameter; 0.060000 -> 0.002000, see "TANSO Level 1Product Description Document" page 3-29) • Orbital data is changed. (predicted value -> fixed value) • Threshold of sun-glint cone angle is changed. (10 degrees -> 5 degrees) • New product items are added.
Version050050	090405–090409 090419–090503 090602–090731 091028–100208	• TIR phase correction (ZPD shift) • New item on spike noise judgment is added. • Threshold of saturation flag is changed. • Low-frequency correction. flag judgment is improved.
Version080080	090731–091001 100208–100316	• Calibration formula of TIR radiance spectrum are added. (But parameters are modified so that radiance values remain the same as those for V050.) • The accuracy of SWIR spike flag judgment is improved. • "CT_obsPoints" value is changed to "0X0a", when sensor mode is "specific point observation". As a result, it can be distinguished from the case of sensor anomaly. • AT/CT error angles are expressed in GOSAT/TANSO sensor coordinate. • Orbit and attitude parameters are changed.
Version100100	090930–091031 100315–110419	• "The major updated point on Ver.100_100 is that TIR phase correction. There are no change in SWIR processing so there is no difference in SWIR spectrum between current Ver.080_080 and Ver.100_100." - e-mail from Akihiro Matsushima
Version130130	110419–120418	• Preliminary Band-1 analog circuit non-linearity correction, based on ADC non-linearity implemented. • Adjustment of saturation detection. • Modification to TIR calibration. • No v2.10 ACOS Level 2 data products produced with this version of GOSAT L1B

Table 4: Description of the different GOSAT L1B releases.

Version	Period YYMMDD	Changes
Version141141	090601-100731	• Modified correction to Band-1 analog circuit non-linearity • Correction to the interferogram sampling interval uniformity • Improvement of TIR phase correction • Improvement of the Band-1 scan speed instability correction for medium gain (Gain M) data. • Processed using the 32-bit Level-1 processing system • No v2.10 ACOS Level 2 data products produced with this version of GOSAT L1B
Version150150	120419-120619	• Identical to v141141, but processed on the 64-bit L1B production processing system
Version150151	090423 – Current date	• Identical to v150150, but with a corrected glint flag. • *All L1B data will be reprocessed to this version by December 2012.

The GOSAT team at JAXA produces GOSAT TANSO-FTS Level 1B (L1B) data products for internal use and for distribution to collaborative partners, such as ESA and NASA. These calibrated products are augmented by the ACOS Project with additional geolocation information and further corrections. These ACOS Level 1B products (with calibrated radiances and geolocation) are the input to the ACOS Level 2 production process.

The distribution of GOSAT and ACOS L1B products is currently restricted by cooperation agreements between JAXA and NASA.

3.4. ACOS Algorithms

In the sections that follow, the following definitions apply:

- Footprint – an observation by a single instrument
- Sounding – a combined observation of all instruments
- Granule – the construct expressing the content of a product (ACOS product granules contain all the processed GOSAT data for a single orbit)

Level 1B Algorithm Overview

The ACOS Level 1B (L1B) algorithm adds additional calibration information to the GOSAT TANSO-FTS Level 1B data, and converts these data to the format needed for the ACOS Level 2 algorithm. For example, the TANSO-FTS L1B is delivered with radiances expressed in engineering units (volts). JAXA provides a series of calibration tables that are used to convert these values from engineering units to the radiometric units used in the ACOS algorithm (photons/m^2/sr/cm^{-1}). The calibration information provided in these tables is derived from pre-launch calibration tests and on-orbit observations of internal light sources, deep space, the sun, the moon, and observations of calibration targets on the surface of the Earth. These tabulated results are assumed to be constant, or used to establish trends for time-dependent corrections.

Sounding and spacecraft geometric variables are included in the ACOS Level 2 products. Starting with v2.9, these geometric data are updated by the ACOS team, based on pointing error estimates provided by the GOSAT Project Team. As noted above, the pointing error tables applied to v2.9 are based on observations collected prior to December 2010, and are assumed to be constant in time. As noted above, the pointing offsets have varied with time. However, these changes have not been incorporated into the ACOS L2 products. The geolocation values reported in v3.3 are typically in error by 1 to 6 km. These errors contribute negligibly to airmass errors over flat surfaces, but could introduce airmass-related biases in regions with significant topographic variability.

ACOS does not currently process all soundings collected by GOSAT. Because the thermal IR data is not utilized in ACOS, only the soundings in the daylight portion of the GOSAT orbit are processed. This version of processing supports both nadir and glint soundings. Only glint soundings are processed over the ocean. Details of glint soundings are provided in section 2.5.2.

In addition, to exclude soundings with inadequate signal, soundings at solar zenith angles greater than 85 degrees are also screened, as indicated by the expression "*sounding_solar_zenith* < 85".

Performing retrievals on scenes containing clouds will either fail or have biased results (depending upon the extent of cloud coverage). Users should check the *cloud_flag* for the ACOS estimate of scene cloudiness. Many cloudy scenes that are inadvertently passed by the cloud screen algorithm will not converge during the processing and, therefore, will not appear in the Level 2 retrieval results.

Level 2 Algorithm Overview

The Full-physics XCO_2 retrieval algorithm was derived from the algorithm developed for the Orbiting Carbon Observatory (OCO). The algorithm is a Rodgers [2000]-type optimal estimation approach and has been described fully in O'Dell *et al*. [2011]. The retrieval algorithm consists of a forward model, an inverse method, and an error analysis step. The overall flow for the retrieval process is shown in Figure 10.

A forward radiative transfer model is used to generate synthetic spectra within the molecular oxygen A-band at 0.76 microns and the weak and strong CO_2 bands centered near 1.61 and 2.06 microns, respectively. . These synthetic spectra are then convolved with the GOSAT instrument line shape and compared to the observed spectra in each of these spectral regions. An inverse model then modifies the assumed atmospheric state to improve the fit to the measured spectra, and the process is repeated until the convergence criteria are met. The forward radiative transfer model contains components simulating the solar spectrum, absorption by CO_2, O_2, H_2O, and other gases, scattering and absorption by clouds and aerosols, reflectance of the surface. Input to the forward model consists of meteorological conditions, surface properties, characteristics of the instrument, etc. . The forward model returns simulated radiance spectra and the partial derivatives of those radiances with respect to properties of the atmospheric and surface state, also called Jacobians.

The residuals between the simulated and measured spectra are minimized by changing the properties of the atmospheric and surface state via the inverse method. This inversion uses the Jacobians to estimate the state changes needed to minimize the differences between the observed and simulated spectra.

Once the atmospheric state yielding the best match to the observed spectrum has been found, the algorithm then determines X_{CO2}, errors in X_{CO2} from different sources (such as vertical smoothing, measurement noise, etc.), and the X_{CO2} column averaging kernel. This is necessary because *xco2* is not itself an element of the state vector. Rather, it is determined from the profile of CO_2 , which is part of the state vector. It is formally given by the total number of CO_2

molecules in the column divided by the total number of dry air molecules in the column. This step is labeled "Error Analysis" in Figure 10.

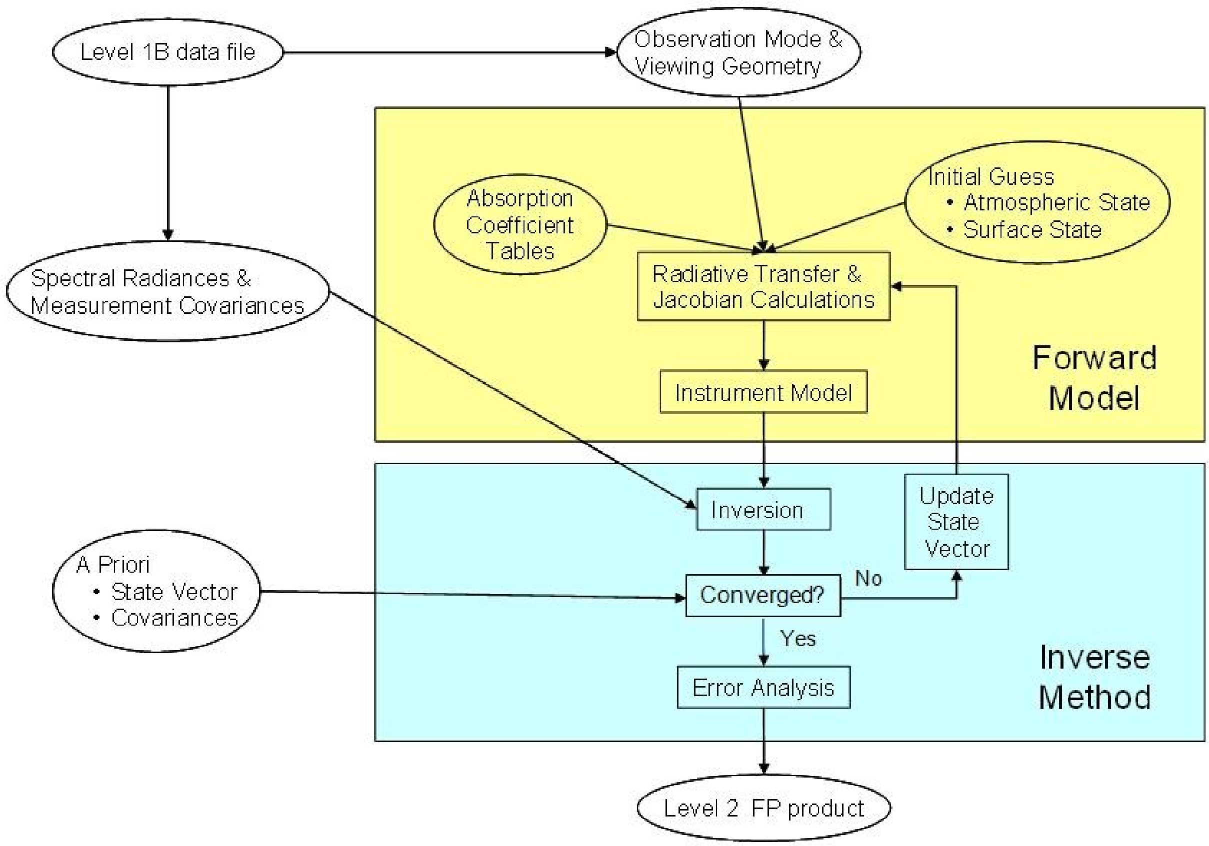

Figure 10. Level 2 Full Physics Retrieval Flow

3.5. ACOS Data Products

The ACOS Level 2 product set consists of products that focus on measuring column-averaged CO_2 dry air mole fraction (X_{CO2}). The measurements are extracted from observations made by JAXA's Greenhouse gases Observing SATellite (GOSAT). The global coverage that is achieved by GOSAT is repeated every three days at the highest resolution yet achieved from orbit.

3.5.1. File Naming Convention

ACOS Level 2 Product file name specification:

acos_ttt_date_nn_collection_productionTimeStamp**.h5**

Where:

- ttt = product type (L2s)
- date = observation date (yymmdd)
- nn = GOSAT path number (01-44)
- collection label, which consists of the following elements:

  - "Production": indicates a production product
  - v[nnn][mmm]: the TANSO-FTS L1B product version where [nnn] is the algorithm version and [mmm] is the parameter version
  - [software component][version] = the software component and version number that created the product. The software component for the final product is always 'L2s'. The version number for this release is '20900'.
  - r[nn] = the reprocessing level; initial production value is always '01'
  - Pol[x] = the polarization used for the retrievals; possible values are S, P, or B (both)
- productionTimeStamp = production date/time (UTC) at ACOS (yymmddhhmmss)

Filename examples:
acos_L2s_090724_07_Production_v110110_L2s2800_r01_PolB_101204185614.h5

acos_L2s_101102_43_Production_v100100_L2s20900_r01_PolB_111002175250.h5

By policy, *collection* will contain the software *build_id*. In addition, *collection* will also contain a data product version *rNN* in case the same product gets regenerated.

3.5.2. File Format and Structure

All ACOS Level 2 product files are in HDF-5 format, developed at the National Center for Supercomputing Applications http://www.hdfgroup.org/. This format facilitates the creation of logical data structures.

All ACOS Level 2 product files contain data structures indexed by sounding (1 to N soundings/file) and are associated by the *sounding_id* variable in all products.

Variables are combined into groups by type (e.g., SoundingGeometry). Within each type, a variable has one or more values per sounding. Variables may be single-valued (e.g., *sounding_altitude*) or multi-valued (e.g., *co2_profile*).

The metadata of each variable describes the variable's attributes, such as dimensions, data representation and units.

3.5.3. Data Definition

The ACOS Level 2 products contain many variables with a variety of dimensions. The following list describes only the most important of the dimensions.

- Retrieval — the number of retrievals reported (those soundings for which retrievals converged or were converging when the maximum number of iterations was reached)
- Polarization — the number of polarization states
- Level — the number of atmospheric retrieval levels
- Exposure — the number of scans in granule
- Band — the number of spectral bands
- Aerosol — the number of retrieval aerosol types

3.5.4. Global Attributes

In addition to variables and arrays of variables, global metadata is stored in the files. Some metadata are required by standard conventions, some are present to meet data provenance requirements and others as a convenience to users of the ACOS Level 2 Products. The most useful global attributes present in all files are shown in Table 5. Table 6 provides a list of key metadata fields for each variable.

Table 5: Some Global Metadata Attributes

Global Attribute	Type	Description
AscendingNodeCrossingDate	String	The date of the ascending node crossing immediately before the first exposure in the TANSO-FTS file. Format: yyyy-mm-dd
AscendingNodeCrossingTime	String	The time of the ascending node crossing immediately before the first exposure in the TANSO-FTS file. Format: hh:mm:ss.sssZ
StartPathNumber	32-bit integer	The first orbital path on which data contained in the product was collected.
StopPathNumber	32-bit integer	The last orbital path on which data contained in the product was collected.
ProductionDateTime	String	The date and time at which the product was created.
CollectionLabel	String	Label associating files in a collection.
HDFVersionId	String	For example 'HDF5 1.8.5'. A character string that identifies the version of the HDF (Hierarchical Data Format) software that was used to generate this data file.
BuildId	String	The identifier of the build containing the software that created the product.
TFTSVersion	String	The version of the TANSO FTS data used to create this data product.

Table 6: Key Metadata Items

Name	Type	Description
Name	String	The name of the variable
Shape	String	The set of dimensions defining the structure
Type	String	The data representation type
Units	String	The units of the variable.
Minimum	String	Smallest valid value of the variable
Maximum	String	Largest valid value of the variable

3.5.5. ACOS Metadata and Variables

This section contains tables describing the groups of variables and metadata elements for the ACOS product.

Changes to elements in v3.3 are highlighted in the tables below.

Table 7: Metadata information

Element	Shape	Storage	Bytes	Repetition	Comment
AncillaryDataDescriptors	AncFile_Array	String	255	5	An array of file names that specifies all of the ancillary data files that were used to generate this output product. Ancillary data sets include all input except for the primary input files.
AscendingNodeCrossingDate	Scalar	String	10	1	The date of the ascending node crossing immediately before the first exposure in the TANSO-FTS file. Format: yyyy-mm-dd
AscendingNodeCrossingTime	Scalar	String	13	1	The time of the ascending node crossing immediately before the first exposure in the TANSO-FTS file. Format: hh:mm:ss.sssZ
AutomaticQualityFlag	Scalar	String	8	1	Reserved for future use.
BuildId	Scalar	String	8	1	The identifier of the build containing the software that created the product.
CollectionLabel	Scalar	String	255	1	Label associating files in a collection
DataFormatType	Scalar	String	8	1	'NCSA HDF' - A character string that describes the internal format of the data product.
FirstSoundingId	Scalar	Int64	8	1	The *sounding_id* of the first sounding in the file
GapStartTime	Gap_Array	String	24	10	Reserved for future use.
GapStopTime	Gap_Array	String	24	10	Reserved for future use.
GranulePointer	Scalar	String	255	1	The name of the product.
HDFVersionId	Scalar	String	3	1	'HDF5 vvvvvvv' - A character string that identifies the version of the HDF (Hierarchical Data Format) software that was used to generate this data file where vvvvvvv is a version id.
InputPointer	InputPtr_Array	String	255	5	The name of the data product that provides the major input that was used to generate this product.
InstrumentShortName	Scalar	String	16	1	'TANSO-FTS' - The name of the instrument that collected the telemetry data.
L2FullPhysicsAlgorithmDescriptor	Scalar	String	255	1	A short description of the Full-Physics algorithm that was used to generate this product
L2FullPhysicsDataVersion	Scalar	String	3	1	Indicates the build version number of the Full-physics algorithm used.

Table 7: Metadata information

Element	Shape	Storage	Bytes	Repetition	Comment
L2FullPhysicsExeVersion	Scalar	String	6	1	Indicates the build version number of the Full-physics algorithm used.
L2FullPhysicsInputPointer	L2FullPhysicsInputPtr_Array	String	255	20	List of the input files used by the Full-physics algorithm code
LastSoundingId	Scalar	Int64	8	1	The *sounding_id* of the last sounding in the file
LongName	Scalar	String	255	1	A complete descriptive name for the product.
MissingExposures	Band_Polarization_Array	Int32	4	6	Number of expected points missing from the dataset
NominalDay	Scalar	String	255	1	The approximate date on which the data were acquired. A *NominalDay* starts at an orbit boundary, so the *NominalDay* for some data do not match their calendar day. Format: yymmdd
NumberOfExposures	Scalar	Int32	4	1	Actual number of points reported in the product
NumberOfGoodRetrievals	Scalar	Int32	4	1	Number of retrievals with master_quality_flag of Good
OrbitOfDay	Scalar	String	255	1	The ordinal number of the orbit within its *NominalDay*, starting with 1.
PlatformLongName	Scalar	String	27	1	'Greenhouse gases Observing SATellite'
PlatformShortName	Scalar	String	3	1	'GOSAT'
PlatformType	Scalar	String	10	1	'spacecraft' - The type of platform associated with the instrument which acquires the accompanying data
ProcessingLevel	Scalar	String	8	1	Indicates processing level. The allowed values are: Level 1A, Level 1B, Level 2
ProducerAgency	Scalar	String	4	1	'NASA' - Identification of the agency that provides the project funding
ProducerInstitution	Scalar	String	3	1	'JPL' - Identification of the institution that provides project management.
ProductionDateTime	Scalar	String	24	1	The date and time at which the product was created.
ProductionLocation	Scalar	String	20	1	Facility in which the file was produced: "Operations Pipeline", "Test Pipeline", "SCF", "Preflight Instrument Characterization", "Development", "Orbital", "Unknown"

Table 7: Metadata information

Element	Shape	Storage	Bytes	Repetition	Comment
ProductionLocationCode	Scalar	String	1	1	One-letter code indicating the *ProductionLocation*. The allowed values are: "" (null string) - Operations Pipeline s - SCF t - Test Pipeline c - Preflight Instrument Characterization d - Development o - Orbital x - Unknown
ProjectId	Scalar	String	3	1	'ACOS' - The project identification string.
QAGranulePointer	Scalar	String	255	1	A pointer to the quality assurance product that was generated with this product.
RangeBeginningDate	Scalar	String	10	1	The date on which the earliest data contained in the product were acquired. Format: yyyy-mm-dd
RangeBeginningTime	Scalar	String	13	1	The time at which the earliest data contained in the product were acquired. Format: hh:mm:ss.sssZ
RangeEndingDate	Scalar	String	10	1	The date on which the latest data contained in the product were acquired. Format: yyyy-mm-dd
RangeEndingTime	Scalar	String	13	1	The time at which the latest data contained in the product were acquired.
RetrievalIterationLimit	Scalar	Int32	4	1	Maximum number of iterations allowed in the implementation of the retrieval algorithm
RetrievalPolarization	Scalar	String	1	1	Polarization used in TANSO-FTS measurements in this granule - "P", "S", or "B" (for Both).
ShortName	Scalar	String	16	1	The short name used to identify all data granules in a given data collection.
SISName	Scalar	String	255	1	The name of the document describing the contents of the product.
SISVersion	Scalar	String	8	1	The version of the document describing the contents of the product.
SizeMBECSDataGranule	Scalar	Float32	4	1	The size of this data granule in Megabytes.
SpectralChannel	Band_Array	String	24	3	The identifier of the spectral regions present in this granule. Allowed values are: '0.76um O2 A-band', '1.6um Weak CO2', '2.06um Strong CO2'
StartPathNumber	Scalar	Int32	4	1	The first orbital path on which data contained in the product was collected.
StopPathNumber	Scalar	Int32	4	1	The last orbital path on which data contained in the product was collected.
TFTSVersion	Scalar	String	6	1	The version of the TANSO FTS data used to create this data product.
VMRO2	Scalar	Float32	4	1	The Volume Mixing Ratio of atmospheric O2 in units of Mole Mole^{-1}

Table 8 describes variables related to the position of the spacecraft at the observation time. Note that the variables have a Shape of 'Retrieval_Array'. Therefore, soundings are included only when retrievals converged or were converging when the maximum number of iterations was reached.

Table 8: Spacecraft geometry variables

Element	Shape	Type	Bytes	Repetition	Unit	Min	Max	Comment
ground_track	Retrieval_Array	Float 32	4	1	Degrees	0	360	Azimuth of the spacecraft ground track (measured from North)
relative_velocity	Retrieval_Array	Float 32	4	1	Meters Second ^{-1}			The component of the relative SC/Target motion along the look-vector.
spacecraft_alt	Retrieval_Array	Float 32	4	1	Meters			Altitude of the spacecraft above the reference ellipsoid at the start of the exposure.
spacecraft_lat	Retrieval_Array	Float 32	4	1	Degrees	-90	90	Geodetic latitude of sub-spacecraft point at the start of the exposure.
spacecraft_lon	Retrieval_Array	Float 32	4	1	Degrees	-180	180	Longitude of sub-spacecraft point at the start of the exposure.
x_pos	Retrieval_Array	Float 32	4	1	Meters			Spacecraft position in Earth Centered Rotating (ECR) coordinates at the start of the exposure.
x_vel	Retrieval_Array	Float 32	4	1	Meters Second ^{-1}			Spacecraft velocity in Earth Centered Rotating (ECR) coordinates at the start of the exposure.
y_pos	Retrieval_Array	Float 32	4	1	Meters			Spacecraft position in Earth Centered Rotating (ECR) coordinates at the start of the exposure.
y_vel	Retrieval_Array	Float 32	4	1	Meters Second ^{-1}			Spacecraft velocity in Earth Centered Rotating (ECR) coordinates at the start of the exposure.
z_pos	Retrieval_Array	Float 32	4	1	Meters			Spacecraft position in Earth Centered Rotating (ECR) coordinates at the start of the exposure.
z_vel	Retrieval_Array	Float 32	4	1	Meters Second ^{-1}			Spacecraft velocity in Earth Centered Rotating (ECR) coordinates at the start of the exposure.

Table 9 describes variables related to the instrument look vector or the intersection of the look vector with the Earth surface. Note that the variables have a Shape of 'Retrieval_Array'. Therefore, soundings are included only when retrievals converged or were converging when the maximum number of iterations was reached.

Table 9: Sounding Geometry Variables

Element	Shape	Type	Bytes	Repetition	Unit	Min	Max	Comment
sounding_altitude	Retrieval_Array	Float 32	4	1	Meters			Mean altitude of the surface within the sounding based on PGS Toolkit topography
sounding_altitude_max	Retrieval_Array	Float 32	4	1	Meters			Maximum altitude of the surface within the sounding based on PGS Toolkit topography
sounding_altitude_min	Retrieval_Array	Float 32	4	1	Meters			Minimum altitude of the surface within the sounding based on PGS Toolkit topography
sounding_altitude_stddev	Retrieval_Array	Float 32	4	1	Meters			Standard deviation of the measure of altitude of the surface within the sounding
sounding_altitude_uncert	Retrieval_Array	Float 32	4	1	Meters			Uncertainty of the measure of altitude of the surface within the sounding based on the accuracy of the input information
sounding_aspect	Retrieval_Array	Float 32	4	1	Degrees	0	360	Azimuth of the surface projection of the slope surface normal
sounding_at_angle	Retrieval_Array	Float 32	4	1	Degrees	-180	180	Angle between the look vector and the spacecraft Y-Z plane. Positive angle is the right-hand screw direction of the Y-axis.
sounding_at_angle_error	Retrieval_Array	Float 32	4	1	Degrees	-180	180	The difference between AT value derived by MMO and actual one is stored
sounding_azimuth	Retrieval_Array	Float 32	4	1	Degrees	0	360	Azimuth of the vector toward the instantaneous position of the spacecraft from the center of the sounding based on topography
sounding_ct_angle	Retrieval_Array	Float 32	4	1	Degrees	-180	180	Angle between look vector and the spacecraft X-Z plane. Positive angle direction is the right-hand screw direction of the X-axis
sounding_ct_angle_error	Retrieval_Array	Float 32	4	1	Degrees	-180	180	The difference between CT value derived by MMO and actual one is stored
sounding_glint_angle	Retrieval_Array	Float 32	4	1	Degrees	0	180	The angle between the vector to the glint spot and the actual look vector.
sounding_land_fraction	Retrieval_Array	Float 32	4	1	Percent	0	100	Percent of land cover within the sounding.
sounding_latitude	Retrieval_Array	Float 32	4	1	Degrees	-90	90	Geodetic latitude of the center of the sounding based on PGS Toolkit topography
sounding_latitude_geoid	Retrieval_Array	Float 32	4	1	Degrees	-90	90	Geodetic latitude of the center of the sounding based on standard geoid
sounding_longitude	Retrieval_Array	Float 32	4	1	Degrees	-180	180	Longitude of the center of the sounding based on PGS Toolkit topography

Table 9: Sounding Geometry Variables

Element	Shape	Type	Bytes	Repetition	Unit	Min	Max	Comment
sounding_longitude_geoid	Retrieval_Array	Float 32	4	1	Degrees	-180	180	Longitude of the center of the sounding based on standard geoid
sounding_plane_fit_quality	Retrieval_Array	Float 32	4	1	Meters			Standard deviation for the tangent plane approximation
sounding_slope	Retrieval_Array	Float 32	4	1	Degrees	0	90	Slope of the best-fit plane to the surface within the sounding.
sounding_solar_azimuth	Retrieval_Array	Float 32	4	1	Degrees	0	360	Azimuth of the sun at the center of the sounding based on topography
sounding_solar_zenith	Retrieval_Array	Float 32	4	1	Degrees	0	90	Angle between the normal to the Earth geoid and the solar angle at the center of the sounding based on topography
sounding_zenith	Retrieval_Array	Float 32	4	1	Degrees	0	90	The angle between the normal to the Earth geoid and the vector toward the instantaneous position of the spacecraft from the center of the sounding based on topography

Table 10 describes Sounding Header fields. They all have the Shape 'Exposure_Array" and, therefore, include all soundings.

Table 10: Sounding Header Variables

Element	Shape	Type	Bytes	Repetition	Comment
cloud_flag	Exposure_Array	Int8	1	1	Estimate of scene visibility for this *sounding_id* taken from an ABO2-only clear sky retrieval: 0 - Clear, 1 - Cloudy, 2 - Undetermined
l2_packaging_qual_flag	Exposure_Array	BitField8	1	1	Bit Flags are used to record the status of each sounding during packaging of l2 output into retrieval arrays. See Table 16.
retrieval_index	Exposure_Array	Int32	4	1	Index into the Retrieval dimension of arrays in the RetrievalResults group for soundings associated with retrievals.
sounding_id	Exposure_Array	Int64	8	1	The unique identifier of the sounding.

Table 11 contains variables that are new in the v3.3 data products.

To further reduce the computation time of retrievals containing clouds, a cloud screening algorithm is applied to this version. It performs a fast, Oxygen A-band only clear-sky retrieval for surface pressure, surface albedo, temperature offset and dispersion multiplier. The retrieved surface pressure and albedo information are combined with the χ^2 goodness-of-fit statistic and signal-to-noise ratio to determine if a scene is clear (0), cloudy (1), or undetermined (2) as shown in Table 10. See Section 6 for a paper on this topic.

Table 11: A-Band-only Retrieval Variables (shading represents that values in this table are new for the v3.3 data products.

Element	Shape	Type	Bytes	Repetition	Comment
albedo_o2_cld	Retrieval_AlbedoO2_Array	Float32	4	2	Retrieved value of lambertian surface albedo at 785 and 755 nm, respectively; from the O2 A Band cloud retrieval.
dispersion_multiplier_cld	Retrieval_Array	Float32	4	1	The retrieved wavenumber multiplier to get the best fit to the O2 A band; from the A Band cloud retrieval.
noise_o2_cld	Retrieval_Array	Float32	4	1	The noise level in the O2 A band for (P+S)/2, averaged over the spectral samples with the ten highest radiance levels.
reduced_chi_squared_o2_cld	Retrieval_Array	Float32	4	1	The reduced chi^2 value of the O2 A-band clear-sky fit used in determine the presence or absence of cloud; from the O2 A Band cloud retrieval.
reduced_chi_squared_o2_threshold_cld	Retrieval_Array	Float32	4	1	The threshold of reduced_chisquared_o2_cld above which cloud_flag is set to 1.
signal_o2_cld	Retrieval_Array	Float32	4	1	The signal level in the O2 A band for (P+S)/2, averaged over the spectral samples with the ten highest radiance levels.
snr_o2_cld	Retrieval_Array	Float32	4	1	The value of the signal-to-noise ratio of (P+S)/2, averaged over the spectral samples with the ten highest radiance levels.
surface_pressure_apriori_cld	Retrieval_Array	Float32	4	1	The value of the surface pressure of the center of GOSAT's field-of-view estimated from ECMWF; from the O2 A Band cloud retrieval.
surface_pressure_cld	Retrieval_Array	Float32	4	1	The retrieved value of the surface pressure; from the O2 A Band cloud retrieval.
surface_pressure_delta_cld	Retrieval_Array	Float32	4	1	surface_pressure_cld - surface_pressure_apriori_cld - surface_pressure_offset_cld
surface_pressure_offset_cld	Retrieval_Array	Float32	4	1	The assumed surface pressure offset for clear-sky soundings, caculated from an empirical relation based on solar zenith angle, land/water and H/M gain; from the O2 A Band cloud retrieval.
temperature_offset_cld	Retrieval_Array	Float32	4	2	The retrieved offset to the assumed profile of temperature taken from the prior (ECMWF) meteorology; from the O2 A Band cloud retrieval.

The IMAP-DOAS fields listed in Table 12 are new in v3.3 data products.

Table 12: IMAP-DOAS retrieval variables **(shading represents that values in this table are new for the v3.3 data products**

Element	Shape	Type	Bytes	Repetition	Comment
ch4_column_apriori_idp	Retrieval_Array	Float32	4	1	A priori vertical column density of CH4 (climatology)
ch4_column_idp	Retrieval_Array	Float32	4	1	Vertical column density of CH4 (weak band)
ch4_column_uncert_idp	Retrieval_Array	Float32	4	1	1-sigma error in the vertical column density of CH4
ch4_weak_band_processing_flag_idp	Retrieval_Array	Int8	1	1	0=processed, 1=failed, 2=not processed
cloud_flag_idp	Retrieval_Array	Int8	1	1	Cloud&Aerosol filter flag; -2=unusable (outside of SZA range); -1=not all retrievals converged; 0=clearly cloudy; 1=probably cloudy; 2=probably clear; 3=very clear
co2_column_apriori_idp	Retrieval_Array	Float32	4	1	A priori vertical column density of CO2 (climatology)
co2_column_ch4_window_idp	Retrieval_Array	Float32	4	1	Vertical column density of CO2 retrieved in the CH4 fit window (very weak lines)
co2_column_strong_band_idp	Retrieval_Array	Float32	4	1	Vertical column density of CO2 (strong band)
co2_column_strong_band_uncert_idp	Retrieval_Array	Float32	4	1	1-sigma error in the vertical column density of CO2 (strong band)
co2_column_weak_band_idp	Retrieval_Array	Float32	4	1	Vertical column density of CO2 (weak band)
co2_column_weak_band_uncert_idp	Retrieval_Array	Float32	4	1	1-sigma error in the vertical column density of CO2
co2_ratio_idp	Retrieval_Array	Float32	4	1	Ratio of retrieved CO2 column (no scattering code) in weak and strong CO2 ban
co2_strong_band_processing_flag_idp	Retrieval_Array	Int8	1	1	0=processed, 1=failed, 2=not processed
co2_weak_band_processing_flag_idp	Retrieval_Array	Int8	1	1	0=processed, 1=failed, 2=not processed
delta_d_idp	Retrieval_Array	Float32	4	1	Deuterium depletion of total column water vapor
delta_d_uncert_idp	Retrieval_Array	Float32	4	1	1-sigma uncertainty in deuterium depletion of total column water vapor
dry_air_column_apriori_idp	Retrieval_Array	Float32	4	1	Integrated vertical column of dry airmass derived from meteorological data
fluorescence_offset_relative_755nm_p_idp	Retrieval_Array	Float32	4	1	Relative fluorescence offset (fraction of continuum level) at 755nm, P-polarization
fluorescence_offset_relative_755nm_p_uncert_idp	Retrieval_Array	Float32	4	1	1-sigma uncertainty in relative fluorescence offset (fraction of continuum level) at 755nm, P-polarization
fluorescence_offset_relative_755nm_s_idp	Retrieval_Array	Float32	4	1	Relative fluorescence offset (fraction of continuum level) at 755nm, S-polarization
fluorescence_offset_relative_755nm_s_uncert_idp	Retrieval_Array	Float32	4	1	1-sigma uncertainty in relative fluorescence offset (fraction of continuum level) at 755nm, S-polarization
fluorescence_offset_relative_771n	Retrieval_	Float3	4	1	Relative fluorescence offset (fraction of

Table 12: IMAP-DOAS retrieval variables **(shading represents that values in this table are new for the v3.3 data products**

Element	Shape	Type	Bytes	Repetition	Comment
m_p_idp	Array	2			continuum level) at 771nm, P-polarization
fluorescence_offset_relative_771nm_p_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in relative fluorescence offset (fraction of continuum level) at 771nm, P-polarization
fluorescence_offset_relative_771nm_s_idp	Retrieval_Array	Float32	**4**	1	Relative fluorescence offset (fraction of continuum level) at 771nm, S-polarization
fluorescence_offset_relative_771nm_s_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in relative fluorescence offset (fraction of continuum level) at 771nm, S-polarization
fluorescence_qual_flag_idp	Retrieval_Array	BitFlag8	**1**	1	bit 0 - 0 good, 1 bad
fluorescence_radiance_755nm_p_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence at 755nm, P-polarization
fluorescence_radiance_755nm_p_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence at 755nm, P-polarization
fluorescence_radiance_755nm_s_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence at 755nm, S-polarization
fluorescence_radiance_755nm_s_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence at 755nm, S-polarization
fluorescence_radiance_771nm_p_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence at 771nm, P-polarization
fluorescence_radiance_771nm_p_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence at 771nm, P-polarization
fluorescence_radiance_771nm_s_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence at 771nm, S-polarization
fluorescence_radiance_771nm_s_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence at 771nm, S-polarization
fluorescence_radiance_mean_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence, both polarization (average of 1.8*771nm and 755nm fluorescence values), to be handled with care
fluorescence_radiance_mean_p_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence, P-polarization (average of 1.8*771nm and 755nm fluorescence values)
fluorescence_radiance_mean_p_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence, P-polarization (average of 1.8*771nm and 755nm fluorescence values)
fluorescence_radiance_mean_s_idp	Retrieval_Array	Float32	**4**	1	Retrieved chlorophyll fluorescence, S-polarization (average of 1.8*771nm and 755nm fluorescence values)
fluorescence_radiance_mean_s_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence, S-polarization (average of 1.8*771nm and 755nm fluorescence values)
fluorescence_radiance_mean_uncert_idp	Retrieval_Array	Float32	**4**	1	1-sigma uncertainty in retrieved chlorophyll fluorescence, both polarization (average of 1.8*771nm and 755nm fluorescence values)
h2o_column_apriori_idp	Retrieval_Array	Float32	**4**	1	A priori vertical column density of H2O (based on ECMWF)
h2o_column_idp	Retrieval_Array	Float32	**4**	1	Vertical column density of H2O

Table 12: IMAP-DOAS retrieval variables **(shading represents that values in this table are new for the v3.3 data products**

Element	Shape	Type	Bytes	Repetition	Comment
h2o_column_uncert_idp	Retrieval_ Array	Float32	4	1	1-sigma error in the vertical column density of H2O
h2o_ratio_idp	Retrieval_ Array	Float32	4	1	Ratio of retrieved H2O column (no scattering code) in weak and strong CO2 band
h2o_ratio_uncert_idp	Retrieval_ Array	Float32	4	1	1-sigma uncertainty in the ratio of retrieved H2O column (no scattering code) in weak and strong CO2 band
hdo_column_apriori_idp	Retrieval_ Array	Float32	4	1	A priori vertical column density of HDO
hdo_column_idp	Retrieval_ Array	Float32	4	1	Vertical column density of HDO
hdo_column_uncert_idp	Retrieval_ Array	Float32	4	1	1-sigma error in the vertical column density of HDO
hdo_h2o_processing_flag_idp	Retrieval_ Array	Int8	4	1	0=processed, 1=failed, 2=not processed
o2_ratio_p_idp	Retrieval_ Array	Float32	4	1	Ratio of retrieved and ECMWF O2 column retrieved in P-polarization
o2_ratio_s_idp	Retrieval_ Array	Float32	4	1	Ratio of retrieved and ECMWF O2 column retrieved in S-polarization
out_of_band_transmission_p_idp	Retrieval_ Array	Float32	4	1	Transmission at the band-pass edge, P-polarization, band 1
out_of_band_transmission_s_idp	Retrieval_ Array	Float32	4	1	Transmission at the band-pass edge, S-polarization, band 1
total_offset_fit_relative_755nm_p_idp	Retrieval_ Array	Float32	4	1	Total offset fit (0-level + fluorescence) as fraction of continuum level (755nm, P polarization)
total_offset_fit_relative_755nm_s_idp	Retrieval_ Array	Float32	4	1	Total offset fit (0-level + fluorescence) as fraction of continuum level (755nm, S polarization)
total_offset_fit_relative_771nm_p_idp	Retrieval_ Array	Float32	4	1	Total offset fit (0-level + fluorescence) as fraction of continuum level (771nm, P polarization)
total_offset_fit_relative_771nm_s_idp	Retrieval_ Array	Float32	4	1	Total offset fit (0-level + fluorescence) as fraction of continuum level (771nm, S polarization)
zero_level_offset_est_relative_755nm_p_idp	Retrieval_ Array	Float32	4	1	Estimated (parameterized) zero level offset contribution to total offset fit (755nm, P polarization)
zero_level_offset_est_relative_755nm_s_idp	Retrieval_ Array	Float32	4	1	Estimated (parameterized) zero level offset contribution to total offset fit (755nm, S polarization)
zero_level_offset_est_relative_771nm_p_idp	Retrieval_ Array	Float32	4	1	Estimated (parameterized) zero level offset contribution to total offset fit (771nm, P polarization)
zero_level_offset_est_relative_771nm_s_idp	Retrieval_ Array	Float32	4	1	Estimated (parameterized) zero level offset contribution to total offset fit (771nm, S polarization)

Table 13 describes the Retrieval Header, providing general characteristics of the soundings retrieved. Soundings are included only when retrievals converged or were converging when the maximum number of iterations was reached.

Table 13: Retrieval header variables

Element	Shape	Type	Bytes	Repetition	Comment
acquisition_mode	Retrieval_Array	String	4	1	The instrument mode in which the data in the product were collected. Valid values are: 'OB1D', 'OB1N', 'OB2D','SPOD','SPON','CALM','LUCA'
ct_observation_points	Retrieval_Array	Int8	1	1	Number of observation points in the cross track direction -1: undefined or specified observation, 0: Electrical Calibration, "0x01" : 1 points "0x03" : 3 points "0x05" : 5 points "0x07" : 7 points "0x09" : 9 points
exposure_duration	Retrieval_Array	Float32	4	1	The duration of the exposure
exposure_index	Retrieval_Array	Int32	4	1	The index into the Exposure dimension of arrays in SoundingHeader, SoundingGeometry, and SpacecraftGeometry groups containing the spectra used to perform the retrieval
gain_swir	Retrieval_Polarization_Array	String	5	2	Instrument gain setting for each polarization: H - High gain, M - Medium gain, L - Low gain, H_ERR - Error in setting high gain, M_ERR - Error in setting medium gain, L_ERR - Error in setting low gain, UNDEF - Gain set to an undefined state
glint_flag	Retrieval_Array	Int8	1	1	This field is incorrect after YYYY-MM-DD. Use the glint filter described in section XXX instead of the glint_flag. Indicates whether GOSAT was in glint mode when acquiring the sounding 0 = Not in glint mode 1 = In glint mode
sounding_id_reference	Retrieval_Array	Int64	8	1	The sounding_id of the sounding containing the spectra used to perform the retrieval
sounding_qual_flag	Retrieval_Array	BitFlag32	4	1	Single-bit quality flags. See Table 16.
sounding_time_string	Retrieval_Array	String	24	1	Representative sounding time, in the format yyyy-mm-ddThh:mm:ss.sssZ
sounding_time_tai93	Retrieval_Array	Float64	8	1	Sounding time in number of SI seconds since midnight, January 1, 1993.
spike_noise_flag	Retrieval_Band_Polarization_Array	Int8	1	6	0 - No spike noise present, 1 - Spike noise present
zpd_saturation_flag	Retrieval_Band_Polarization_Array	Int8	1	6	Copy exposureAttribute/pointAttribute/RadiometricCorrectionInfo/ZPD_SatiratopmFlag_SWIR

Table 14 describes variables expressing the retrieval results. Note that some of the variables have a Shape including 'Retrieval'. Therefore, soundings are included only when retrievals converged or were converging when the maximum number of iterations was reached.

In Table 14, X_{CO2} is calculated in the following way:

$$xco2 = \sum_{i=1}^{N_{num\_levels}} W_i CO2_i$$

where W_i represents *xco2_pressure_weighting_function* and $CO2_i$ represents *co2_profile*. The sum is over *num_levels*. W_i is a function primarily of the pressure level spacing, but also weakly of water vapor, and also depends on surface pressure.

Table 14: Variables expressing retrieval results

Element	Shape	Type	Byte s	Repeti tion	Unit	Comment
aerosol_ice_aod	Retrieval_Array	Float 32	4	1		Retrieved total column-integrated aerosol optical depth for water aerosol type
aerosol_ice_aod_high	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for water aerosol type for pressure levels less than 50,000 Pa
aerosol_ice_aod_low	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for water aerosol type for pressure levels greater than 80000 Pa
aerosol_ice_aod_mid	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for water aerosol type for pressure levels between 50,000 and 80,000 Pa
aerosol_ice_gaussian_log_param	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Retrieved gaussian log parameters for water aerosol type [total log aod, center pressure/surf-pressure, pressure sigma/surf-pressure]
aerosol_ice_gaussian_log_param_apriori	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Apriori of retrieved gaussian log parameters for water aerosol type
aerosol_ice_gaussian_log_param_uncert	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Uncertainty of retrieved gaussian log parameters for water aerosol type

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
aerosol_kahn_2b_aod	Retrieval_Array	Float 32	4	1		Retrieved total column-integrated aerosol optical depth for Kahn 2b aerosol type
aerosol_kahn_2b_aod_high	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for Kahn 2b aerosol type for pressure levels less than 50,000 Pa
aerosol_kahn_2b_aod_low	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for Kahn 2b aerosol type for pressure levels greater than 80,000 Pa
aerosol_kahn_2b_aod_mid	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for Kahn 2b aerosol type for pressure levels between 50,000 and 80,000 Pa
aerosol_kahn_2b_gaussian_log_param	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Retrieved gaussian log parameters for Kahn 2b aerosol type [total log aod, center pressure/surf-pressure, pressure sigma/surf-pressure]
aerosol_kahn_2b_gaussian_log_param_apriori	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Apriori of retrieved gaussian log parameters for Kahn 2b aerosol type
aerosol_kahn_2b_gaussian_log_param_uncert	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Uncertainty of retrieved gaussian log parameters for Kahn 2b aerosol type
aerosol_kahn_3b_aod	Retrieval_Array	Float 32	4	1		Retrieved total column-integrated aerosol optical depth for Kahn 3b aerosol type
aerosol_kahn_3b_aod_high	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for Kahn 3b aerosol type for pressure levels less than 50,000 Pa
aerosol_kahn_3b_aod_low	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for Kahn 3b aerosol type for pressure levels greater than 80,000 Pa

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
aerosol_kahn_3b_aod_mid	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for Kahn 3b aerosol type for pressure levels between 50,000 and 80,000 Pa
aerosol_kahn_3b_gaussian_log_param	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Retrieved gaussian log parameters for Kahn 3b aerosol type [total log aod, center pressure/surf-pressure, pressure sigma/surf-pressure]
aerosol_kahn_3b_gaussian_log_param_apriori	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Apriori of retrieved gaussian log parameters for Kahn 3b aerosol type
aerosol_kahn_3b_gaussian_log_param_uncert	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Uncertainty of retrieved gaussian log parameters for Kahn 3b aerosol type
aerosol_total_aod	Retrieval_Array	Float 32	4	1		Retrieved total column-integrated aerosol optical depth for all aerosol types
aerosol_total_aod_high	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for all aerosol types for pressure levels less than 50,000 Pa
aerosol_total_aod_low	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for all aerosol types for pressure levels greater than 80,000 Pa
aerosol_total_aod_mid	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for all aerosol types for pressure levels between 50,000 and 80,000 Pa
aerosol_water_aod	Retrieval_Array	Float 32	4	1		Retrieved total column-integrated aerosol optical depth for ice aerosol type
aerosol_water_aod_high	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for ice aerosol type for pressure levels less than 50,000 Pa
aerosol_water_aod_low	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for ice aerosol type for pressure levels greater than 80,000 Pa

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
aerosol_water_aod_mid	Retrieval_Array	Float 32	4	1		Retrieved column-integrated aerosol optical depth for ice aerosol type for pressure levels between 50,000 and 80,000 Pa
aerosol_water_gaussian_log_param	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Retrieved gaussian log parameters for ice aerosol type [total log aod, center pressure/surf-pressure, pressure sigma/surf-pressure]
aerosol_water_gaussian_log_param_apriori	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Apriori of retrieved gaussian log parameters for ice aerosol type
aerosol_water_gaussian_log_param_uncert	Retrieval_AerosolGaussianLogParam_Array	Float 32	4	3		Uncertainty of retrieved gaussian log parameters for ice aerosol type
albedo_aprioiri_strong_co2_fph	Retrieval_Array	Float 32	4	1		Apriori of retrieved Lambertian componet of albedo at 2.06 microns
albedo_apriori_o2_fph	Retrieval_Array	Float 32	4	1		Apriori of retrieved Lambertian component of albedo at 0.77 microns
albedo_apriori_weak_co2_fph	Retrieval_Array	Float 32	4	1		Apriori of retrieved Lambertian component of albedo at 1.615 microns
albedo_o2_fph	Retrieval_Array	Float 32	4	1		Retrieved Lambertian component of albedo at at 0.77 microns
albedo_slope_apriori_o2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Apriori of retrieved spectral dependence of Lamberion component of albedo within o2 channel
albedo_slope_apriori_strong_co2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Apriori of spectral dependence of Lamberion component of albedo within strong co2 channel
albedo_slope_apriori_weak_co2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Apriori of retrieved spectral dependence of Lamberion component of albedo within weak co2 channel
albedo_slope_o2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Retrieved spectral dependence of Lamberion component of albedo within o2 channel

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
albedo_slope_strong_co2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Retrieved spectral dependence of Lamberion component of albedo within strong co2 channel
albedo_slope_uncert_o2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Uncertainty of retrieved spectral dependence of Lamberion component of albedo within o2 channel
albedo_slope_uncert_strong_co2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Uncertainty of spectral dependence of Lamberion component of albedo within strong co2 channel
albedo_slope_uncert_weak_co2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Uncertainty of retrieved spectral dependence of Lamberion component of albedo within weak co2 channel
albedo_slope_weak_co2	Retrieval_Array	Float 32	4	1	Wavenumber^{-1}	Retrieved spectral dependence of Lamberion component of albedo within weak co2 channel
albedo_strong_co2_fph	Retrieval_Array	Float 32	4	1		Retrieved Lambertian component of albedo at 2.06 microns
albedo_uncert_o2_fph	Retrieval_Array	Float 32	4	1		Uncertainty of retrieved Lambertian component of albedo at 0.77 microns
albedo_uncert_strong_co2_fph	Retrieval_Array	Float 32	4	1		Uncertainty of retrieved Lambertian component of albedo at 2.06 microns
albedo_uncert_weak_co2_fph	Retrieval_Array	Float 32	4	1		Uncertainty of retrieved Lambertian componet of albedo at 1.615 microns
albedo_weak_co2_fph	Retrieval_Array	Float 32	4	1		Retrieved Lambertian component of albedo at 1.615 microns
apriori_o2_column	Retrieval_Array	Float 32	4	1	Molecules Meters^{-2}	Apriori vertical column of O2
co2_profile	Retrieval_Level_Array	Float 32	4	20	Mole Mole^{-1}	Vertical profile of CO_2
co2_profile_apriori	Retrieval_Level_Array	Float 32	4	20	Mole Mole^{-1}	Vertical apriori profile of CO_2
co2_profile_averaging_kernel_matrix	Retrieval_Level_Array	Float 32	4	4000		Averaging kernel for co2 profile
co2_profile_covariance_matrix	Retrieval_Level_Array	Float 32	4	4000	Mole^{2} Mole^{-2}	Covariance matrix for co2 profile

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
co2_profile_uncert	Retrieval_Level_Array	Float 32	4	20	Mole Mole^{-1}	Vertical profile of CO_2 uncertainty
dispersion_offset_apriori_o2	Retrieval_Array	Float 64	8	1	cm^{-1}	Apriori of retrieved spectral shift in o2 channel
dispersion_offset_apriori_strong_co2	Retrieval_Array	Float 64	8	1	cm^{-1}	Apriori of retrieved dispersion offset term in strong co2 channel
dispersion_offset_apriori_weak_co2	Retrieval_Array	Float 64	8	1	cm^{-1}	Apriori of retrieved dispersion offset term in weak co2 channel
dispersion_offset_o2	Retrieval_Array	Float 64	8	1	cm^{-1}	Retrieved dispersion offset term in o2 channel
dispersion_offset_strong_co2	Retrieval_Array	Float 64	8	1	cm^{-1}	Retrieved dispersion offset term in strong co2 channel
dispersion_offset_uncert_o2	Retrieval_Array	Float 32	4	1	cm^{-1}	Uncertainty of retrieved dispersion offset term in o2 channel
dispersion_offset_uncert_strong_co2	Retrieval_Array	Float 32	4	1	cm^{-1}	Uncertainty of retrieved dispersion offset term in strong co2 channel
dispersion_offset_uncert_weak_co2	Retrieval_Array	Float 32	4	1	cm^{-1}	Uncertainty of retrieved dispersion offset term in weak co2 channel
dispersion_offset_weak_co2	Retrieval_Array	Float 64	8	1	cm^{-1}	Retrieved dispersion offset term in weak co2 channel
diverging_steps	Retrieval_Array	Int16	2	1		Number of iterations in which solution diverged
dof_co2_profile	Retrieval_Array	Float 32	4	1		Degrees of freedom (target gas profile only)
dof_full_vector	Retrieval_Array	Float 32	4	1		Degrees of freedom (Full state vector)
eof_1_scale_apriori_o2	Retrieval_Array	Float 32	4	1		Apriori of retrieved scale factor of first empirical orthogonal residual function in o2 channel
eof_1_scale_apriori_strong_co2	Retrieval_Array	Float 32	4	1		Apriori of retrieved scale factor of first empirical orthogonal residual function in strong co2 channel
eof_1_scale_apriori_weak_co2	Retrieval_Array	Float 32	4	1		Apriori of retrieved scale factor of first empirical orthogonal residual function in weak co2 channel

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
eof_1_scale_o2	Retrieval_Array	Float 32	4	1		Retrieved scale factor of iirst empirical orthogonal residual function in o2 channel
eof_1_scale_strong_co2	Retrieval_Array	Float 32	4	1		Retrieved scale factor of first empirical orthogonal residual function in strong co2 channel
eof_1_scale_uncert_o2	Retrieval_Array	Float 32	4	1		Uncertaintly of retrieved scale factor of first empirical orthogonal residual function in o2 channel
eof_1_scale_uncert_strong_co2	Retrieval_Array	Float 32	4	1		Uncertaintly of retrieved scale factor of first empirical orthogonal residual function in strong o2 channel
eof_1_scale_uncert_weak_co2	Retrieval_Array	Float 32	4	1		Uncertaintly of retrieved scale factor of first empirical orthogonal residual function in weak o2 channel
eof_1_scale_weak_co2	Retrieval_Array	Float 32	4	1		Retrieved scale factor of first empirical orthogonal residual function in weak co2 channel
fluorescence_at_reference	Retrieval_Array	Float 32	4	1	W cm{-2} sr^{-1} (cm^{-1})^{-1}	Retrieved fluorescence at 0.755 microns
fluorescence_at_reference_apriori	Retrieval_Array	Float 32	4	1	W cm{-2} sr^{-1} (cm^{-1})^{-1}	Apriori of retrieved fluorescence at 0.755 microns
fluorescence_at_reference_uncert	Retrieval_Array	Float 32	4	1	W cm{-2} sr^{-1} (cm^{-1})^{-1}	Uncertainty of retrieved fluorescence at 0.755 microns
fluorescence_slope	Retrieval_Array	Float 32	4	1	W cm{-2} sr^{-1} (cm^{-1})^{-2}	Retrieved fluorescence slope at 0.755 microns
fluorescence_slope_apriori	Retrieval_Array	Float 32	4	1	W cm{-2} sr^{-1} (cm^{-1})^{-2}	Apriori of retrieved fluorescence slope at 0.755 microns
fluorescence_slope_uncert	Retrieval_Array	Float 32	4	1	W cm{-2} sr^{-1} (cm^{-1})^{-2}	Uncertainty of retrieved fluorescence slope at 0.755 microns
h2o_scale_factor	Retrieval_Array	Float 32	4	1		Retrieved scale factor for h2o profile
h2o_scale_factor_apriori	Retrieval_Array	Float 32	4	1		Apriori of retrieved scale factor for h2o profile
h2o_scale_factor_uncert	Retrieval_Array	Float 32	4	1		Uncertainty of retrieved scale factor for h2o profile
iterations	Retrieval_Array	Int16	2	1		Number of iterations

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
last_step_levenberg_marquardt_parameter	Retrieval_Array	Float 32	4	1		Levenberg Marquardt parameter corresponding to last iteration
num_active_levels	Retrieval_Array	Int16	2	1		Number of levels in atmospheric model
outcome_flag	Retrieval_Array	Int8	1	1		Flag indication full physics outcome (more elaboration here)
quality_flag	Retrieval_Array	String	8	1		A string field with 4 possible values: "Good", "Caution" and "Bad", and a fourth value of "Failed" if a problem is seen in the sounding while it is being aggregated into the HDF product. Fixed length string, blank padded plus a null termination.
retrieved_co2_column	Retrieval_Array	Float 32	4	1	Molecules Meters^{-2}	Retrieved vertical column of CO2
retrieved_dry_air_column_layer_thickness	Retrieval_Layer_Array	Float 32	4	19	Molecules Meters^{-2}	Retrieved vertical column of dry air per atmospheric layer
retrieved_h2o_column	Retrieval_Array	Float 32	4	1	Molecules Meters^{-2}	Retrieved vertical column of H2O
retrieved_h2o_column_layer_thickness	Retrieval_Layer_Array	Float 32	4	19	Molecules Meters^{-2}	Retrieved vertical column of H2O per atmospheric layer
retrieved_o2_column	Retrieval_Array	Float 32	4	1	Molecules Meters^{-2}	Retrieved vertical column of O2
retrieved_wet_air_column_layer_thickness	Retrieval_Layer_Array	Float 32	4	20	Molecules Meters^{-2}	Retrieved vertical column of wet air per atmospheric layer
specific_humidity_profile_ecmwf	Retrieval_ECMWFLevel_Array	Float 32	4	91	Kilogram Kilogram^{-1}	ECMWF specific humidity profile interpolated to observation location, time
surface_pressure_apriori_fph	Retrieval_Array	Float 32	4	1	Pascals	Apriori of surface pressure
surface_pressure_fph	Retrieval_Array	Float 32	4	1	Pascals	Surface pressure
surface_pressure_uncert_fph	Retrieval_Array	Float 32	4	1	Pascals	Apriori of surface pressure

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
surface_type	Retrieval_Array	String	19	1		"Lambertian" or " Coxmunk,Lambertian" This element can be used to determine whether a sounding is in glint mode (Coxmunk,Lambertian) or nadir (Lambertian).
temperature_offset_apriori_fph	Retrieval_Array	Float 32	4	1	Kelvin	Apriori of retrieved offset of temperature profile
temperature_offset_fph	Retrieval_Array	Float 32	4	1	Kelvin	Retrieved offset of temperature profile
temperature_offset_uncert_fph	Retrieval_Array	Float 32	4	1	Kelvin	Uncertainty of retrieved offset of temperature profile
temperature_profile_ecmwf	Retrieval_ECMWFLevel_Array	Float 32	4	91	Kelvin	ECMWF temperature profile interpolated to observation location, time
vector_pressure_levels	Retrieval_Level_Array	Float 32	4	20	Pascals	Pressure altitude corresponding to each atmospheric level
vector_pressure_levels_apriori	Retrieval_Level_Array	Float 32	4	20	Pascals	
vector_pressure_levels_ecmwf	Retrieval_ECMWFLevel_Array	Float 32	4	91	Pascals	Pressure altitude corresponding to each ECMWF atmospheric level
wind_speed	Retrieval_Array	Float 32	4	1	Meters Second^{-1}	Retrieved Cox-Munk wind speed
wind_speed_apriori	Retrieval_Array	Float 32	4	1	Meters Second^{-1}	Apriori of retrieved Cox-Munk wind speed
wind_speed_uncert	Retrieval_Array	Float 32	4	1	Meters Second^{-1}	Uncertainty of retrieved Cox-Munk wind speed
xco2	Retrieval_Array	Float 32	4	1	Mole Mole^{-1}	Column-averaged CO2 dry air mole fraction
xco2_apriori	Retrieval_Array	Float 32	4	1	Mole Mole^{-1}	Apriori of column-averaged CO2 dry air mole fraction.
xco2_avg_kernel	Retrieval_Level_Array	Float 32	4	20		Column averaging kernel
xco2_avg_kernel_norm	Retrieval_Level_Array	Float 32	4	20		Normalized column averaging kernel
xco2_pressure_weighting_function	Retrieval_Level_Array	Float 32	4	20		Pressure weighting function to form xco2
xco2_uncert	Retrieval_Array	Float 32	4	1	Mole Mole^{-1}	Error in column averaged target gas dry air mole fraction
xco2_uncert_interf	Retrieval_Array	Float 32	4	1	Mole Mole^{-1}	Variance of target gas due to interference

Table 14: Variables expressing retrieval results

Element	Shape	Type	Bytes	Repetition	Unit	Comment
xco2_uncert_noise	Retrieval_Array	Float 32	4	1	Mole Mole^{-1}	Variance of target gas due to noise
xco2_uncert_smooth	Retrieval_Array	Float 32	4	1	Mole Mole^{-1}	Variance of target gas due to smoothing
zero_level_offset_apriori_o2	Retrieval_Array	Float 32	4	1	10^{-9} W cm{-2} sr^{-1} (cm^{-1})^{-1}	Apriori of retrieved zero level offset in o2 channel
zero_level_offset_o2	Retrieval_Array	Float 32	4	1	10^{-9} W cm{-2} sr^{-1} (cm^{-1})^{-1}	Retrieved zero level offset in o2 channel
zero_level_offset_uncert_o2	Retrieval_Array	Float 32	4	1	10^{-9} W cm{-2} sr^{-1} (cm^{-1})^{-1}	Uncertainty of retrieved zero level offset in o2 channel

Table 15 describes variables related to the analysis of the three spectral regions. Note that the variables have a Shape including 'Retrieval'. Therefore, soundings are included only when retrievals converged or were converging when the maximum number of iterations was reached.

In the descriptions below, "Reduced chi squared" is defined as:

$$\chi_r^2 = \frac{1}{N_{chan} - 5} \sum_{i=1}^{N_{chan}} \frac{(y_i - f_i(\hat{x})}{\sigma_i^2}$$

where N_{chan} is the number of GOSAT channels in the spectral region, y_i is the radiance value measured by GOSAT in channel i, σ_i^2 is the square of the uncertainty (or noise) in channel i, and $f_i(x)$ is the model of the radiance in channel i.

Table 15: Spectral parameter variables

Element	Shape	Type	Bytes	Repetition	Unit	Comment
noise_o2_fph	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	
noise_strong_co2_fph	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	
noise_weak_co2_fph	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	
reduced_chi_squared_o2_fph	Retrieval_Array	Float 32	4	1		Reduced chi squared of spectral fit for ABO2 spectral region
reduced_chi_squared_strong_co2_fph	Retrieval_Array	Float 32	4	1		Reduced chi squared of spectral fit for Strong CO2 spectral region
reduced_chi_squared_weak_co2_fph	Retrieval_Array	Float 32	4	1		Reduced chi squared of spectral fit for Weak CO2 spectral region

Table 15: Spectral parameter variables

Element	Shape	Type	Bytes	Repetition	Unit	Comment
relative_residual_mean_square_o2	Retrieval_Array	Float 32	4	1		Root mean squares of residuals over signal, i.e. sqrt [1/N * Sum[((MeasuredRadiance – ModelRadiance)/signal)^2] where N is the number of spectral elements in the band
relative_residual_mean_square_strong_co2	Retrieval_Array	Float 32	4	1		Root mean squares of residuals over signal, i.e. sqrt [1/N * Sum[((MeasuredRadiance – ModelRadiance)/signal)^2] where N is the number of spectral elements in the band
relative_residual_mean_square_weak_co2	Retrieval_Array	Float 32	4	1		Root mean squares of residuals over signal, i.e. sqrt [1/N * Sum[((MeasuredRadiance – ModelRadiance)/signal)^2] where N is the number of spectral elements in the band
residual_mean_square_o2	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	Root mean squares of residuals
residual_mean_square_strong_co2	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	Root mean squares of residuals
residual_mean_square_weak_co2	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	Root mean squares of residuals
signal_o2_fph	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	the signal level representative of the continuum level for this spectrum.
signal_strong_co2_fph	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	The signal level representative of the continuum level for this spectrum.
signal_weak_co2_fph	Retrieval_Array	Float 32	4	1	W cm^{-2} sr^{-1} (cm^{-1})^{-1}	the signal level representative of the continuum level for this spectrum.
snr_o2_l1b	Retrieval_Polarization_Array	Float 32	4	2		Signal-to-noise ratio for ABO2 spectral region . from the L1b processing
snr_strong_co2_l1b	Retrieval_Polarization_Array	Float 32	4	2		Signal-to-noise ratio for Strong CO2 spectral region
snr_weak_co2_l1b	Retrieval_Polarization_Array	Float 32	4	2		Signal-to-noise ratio for Weak CO2 spectral region

Table 16 describes bit definitions for the three variables that are constructed as bit flags.

Table 16: Bit flag definitions

Element	Bit #	Content
l2_packaging_qual_flag	0	Spare
	1	Spare
	2	excluded during sounding selection
	3	skipped due to missing sounding file
	4	skipped due to failed sounding file pre-check
	5	failed due to sounding file read error
	6	Spare
	7	failed due to unexpected packaging error
sounding_qual_flag	0	Radiance calibration 0 = At least one band succeeded at least partially 1 = All three bands failed
	1	Geolocation 0 = Sounding geolocation succeeded 1 = Sounding geolocation failed
	2	Radiance calibration 0 = All three bands succeeded 1 = At least one band failed in at least one color
	3	Sounding geometry 0 = All parameters derived successfully 1 = Derivation failed
	4	Band ABO2 radiance calibration 0 = Successful 1 = At least on one color failed
	5	Band WCO2 radiance calibration 0 = Successful 1 = At least on one color failed
	6	Band SCO2 radiance calibration 0 = Successful 1 = At least on one color failed
	7	Sounding time derivation 0 = Successful 1 = Failed
	8	Derivation of surface parameters using DEM 0 = Successful 1 = Some parameters could not be derived
	9	Spacecraft position and velocity derivation 0 = Successful 1 = Failed
	10-31	Spare
fluorescence_qual_flag_idp	0	TBD 0= Good 1 = Bad

4. Tools and Data Services

HDFView

HDFView is a Java based graphical user interface created by the HDF Group that can be used to browse all ACOS HDF products. The utility allows users to view all objects in an HDF file hierarchy, which is represented as a tree structure. HDFView can be downloaded or support found at: http://www.hdfgroup.org/hdf-java-html/hdfview/.

Mirador

The GES DISC provides basic temporal, advanced (event), and spatial searches through its search and download engine, Mirador (http://mirador.gsfc.nasa.gov). Mirador offers various download options that suit users with different preferences and different levels of technical skills. Users can start from a point where they don't know anything about these particular data, its location, size, format, etc., to quickly find what they need by just providing relevant keywords, like "ACOS", or "CO2".

Here is a direct link to the v2.9 ACOS science products on this site:

http://mirador.gsfc.nasa.gov/cgi-bin/mirador/collectionlist.pl?search=1&keyword=acos_l2s+2.9

Here are 2 methods to download the v2.9 collection:

1) Mirador Webpage

- Clicking the link above will display the collection for 2.9. Beneath the collection name, click the link "View Files"; this link will display all the files for v2.9. From here, click in the checkbox(es) to select the file(s) of interest. Click one of the buttons at the top to add the file(s) to the Cart. Doing this will update the page to show the data set collection name. On the Shopping Cart page, click the "Checkout" button. This will display the Download Data page with instructions on how to download the selected products.

2) Command-line

To build a list of ftp-paths to data files from the v2.9 collection, run the following Unix command:

```
wget "http://mirador.gsfc.nasa.gov/cgi-bin/mirador/granlist.pl?page=1&dataSet=ACOS_L2S&version=2.9&location=%28-90,-180%29,%2890,180%29&startTime=2009-03-30&endTime=2011-12-30&format=rss&maxgranules=100000" -nv -O - | sed -n '/>ftp:/ s|*</*link>||gp'
```

Note the time constrains, and the version, that can be changed as appropriate. The acquired list of ftp-paths to the data files can be used in a number of ways to download the files. The most convenient would be to use "wget" from Unix command-line:

wget –i list_of_files.txt

where the list of the ftp-paths was stored in the text file "list_of_files.txt"

Global Change Master Directory

Information about GOSAT/ACOS data can be researched alongside with other relevant collections in GCMD (Global Change Master Directory):

http://gcmd.nasa.gov/

or

http://gcmd.gsfc.nasa.gov/getdif.htm?GES_DISC_ACOS_L2S_V2.9

5. Contact Information

Contact information of the producer of the data products:

ACOS operations team: gdsops@nephthys.jpl.nasa.gov

Contact information for interpretation and usage of the data products:

ACOS data team: acos@jpl.nasa.gov

The following list is of related organizations, web sites or publications that may be beneficial to the user.

- Japanese Aerospace Exploration Agency:
  - http://www.jaxa.jp/projects/sat/gosat/index_e.html
- Japanese National Institute for Environmental Studies:
  - http://www.gosat.nies.go.jp/index_e.html

6. Acknowledgements, References and Documentation

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Links

The following list provides references to relevant documentation that users may find helpful.

- General GOSAT information:
  - http://www.jaxa.jp/projects/sat/gosat/index_e.html
  - http://www.gosat.nies.go.jp/index_e.html
  - http://www.gosat.nies.go.jp/eng/GOSAT_pamphlet_en.pdf
- Level 2 algorithm information:
  - ACOS Level 2 Algorithm Theoretical Basis Document, JPL D-65488
- Releases and publications:
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- Frankenberg, C., Fisher, J., Worden, J., Badgley, G., Saatchi, S., Lee, J.-E., et al. (2011). New global observations of the terrestrial carbon cycle from GOSAT: Patterns of plant fluorescence with gross primary productivity. Geophysical Research Letters, 38(17), L17706.
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Validation

Papers related to validation of the ACOS data product, plans for OCO-2 data validation or the TCCON network:

- Wunch et al., The Total Carbon Column Observing Network, Phil. Trans. R. Soc. A, 369, 2087–2112, doi:10.1098/rsta.2010.0240, 2011a.
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